Saskatchewan
Research Council

INTENSIVE CAGE CULTURE OF RAINBOW TROUT IN FARM DUGOUTS

by

W.W. Sawchyn

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EXECUTIVE SUMMARY

Aquaculture in the prairie provinces presently consists of stocking rainbow trout in prairie winterkill lakes and allowing them to grow to marketable size by freeze up. In 1982, 1888 individuals obtained licenses to stock private waters in Saskatchewan. Of these only 52 were commercial licenses which allowed the production of fish for resale.

This type of put-and-take fishery involves minimum effort on the part of the fisherman but also allows few guarantees with respect to harvest success, fish size and quality and makes fish available at only one time of the year. For example, fish recoveries for both private and commercial fish farmers in 1982 were only 36%.

This study undertook to investigate the feasibility of intensive culture of rainbow trout in farm dugouts in a manner similar to feed lot operations. Intensive fish culture would guarantee near 100% recovery; it would provide controlled production with respect to product size, quality and availability; it would maximize use of available water supplies for aquaculture.

Rainbow trout were stocked in cages in lined dugouts for two successive years. Results of this study show that trout can be successfully reared on artificial feed to market size in five months. Ponds can sustain a stocking density of 15 times that of a typical put-and-take fishery for successive years. Because the fish are held in cages, fish recoveries are near 100% with minimal effort allowing considerable flexibility with respect to size selection and processing to meet market requirements. Stocking densities of up to 3000 fish per dugout; or 30 times typical stocking rates are possible under carefully managed conditions.

This report describes in detail the results of the first two years of operation outlining successes and failures which may serve as a guide for new commercial operations and further research.

ACKNOWLEDGEMENTS

This project was undertaken as one of Saskatchewan Research Council's core research programs designed to promote the development of new industries in Saskatchewan. We are indebted to Dr. E. Coxworth, K.R. Bindle and J. Whiting for their enthusiastic support of the project. Key participants in the field program were Barry Paquin and Dan Richert. They were assisted by R. Begrand, R. Godwin, and J. Polson.

Instrumentation design and manufacture was undertaken by B. Smith, K.R. Bindle and R. MacPherson.

We are indebted to the above plus many others who through their efforts and initiatives in this project are assisting in promoting a dynamic aquaculture industry in Saskatchewan.

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1 INTRODUCTION

In 1968 the Freshwater Institute began a study of the feasibility of rearing rainbow trout (Salmo gairdneri) in prairie winterkill lakes. They demonstrated that fingerlings of 3-4 g stocked in May and harvested in October were capable of growing to a marketable size, greater than 200 g, in one season. This demonstration resulted in the development of a small but dynamic cottage industry. In 1982, 1888 individuals obtained licences to stock private waters in Saskatchewan alone (Table 1, from Saskatchewan Fish Farm Review, 1982). Of these, 52 were commercial licences which allow resale of fish. The remainder produced fish for domestic consumption and recreation.

The 1982 trout stocking program utilized approximately 685,000 fingerlings distributed among the private and commercial fishermen in proportions of 63% and 37%, respectively (Saskatchewan Fish Farm Review, 1982). These were stocked in approximately 2500 hectares of water bodies ranging from farm dugouts to sloughs and small lakes. Recoveries for both private and commercial fish farmers averaged about 36%.

Commercial fish farming resulted in sales of approximately 29,000 kilograms with an estimated value of $130,000.

The above statistics demonstrate enthusiastic support for a pothole fishery in Saskatchewan with modest success in developing the fishery into commercial enterprises. It is with regard to the latter that the Saskatchewan Research Council has undertaken to apply existing and innovative approaches to pothole fish culture which would enhance production and strive to achieve provincial self sufficiency. This report describes the results of the first two years of research into the development and application of intensive pond culture to the pothole fishery.

Table 1. Number of Licences and Licencees (in brackets) Issued for Rainbow Trout Culture in Saskatchewan[1].

Year	Private	Commercial	Total
1970	144 (130)	22 (17)	166 (147)
1971	446 (390)	36 (30)	482 (420)
1972	894 (781)	40 (37)	934 (818)
1973	1,223 (1,075)	41 (36)	1,264 (1,111)
1974	2,370 (2,180)	42 (37)	2,412 (2,217)
1975	2,492 (2,246)	46 (39)	2,538 (2,285)
1976	2,409 (2,210)	57 (50)	2,446 (2,260)
1977	1,918 (1,733)	57 (51)	1,975 (1,784)
1978	2,077 (1,895)	57 (53)	2,134 (1,948)
1979	2,274 (2,114)	57 (53)	2,331 (2,167)
1980	2,097 (1,936)	57 (52)	2,154 (1,988)
1981	1,698 (1,568)	55 (54)	1,753 (1,622)
1982	1,973 (1,836)	52 (52)	2,025 (1,888)

[1]From "Saskatchewan Fish Farm Review 1982".

2 OBJECTIVES

An evaluation of the prairie pothole fishery shows it to be primarily a hobby fishery supplying small quantities of fish to the producer and his friends and providing some opportunities for recreational fishing. Several factors inherent in the approach limit the potential of the fishery:

(1) The fishery makes use of dugouts, sloughs, reservoirs and small lakes which under normal circumstances winter kill fish through dissolved oxygen depletion and as such are not capable of sustaining natural fish populations. The grow-out period is, therefore, limited to the open-water season which generally extends from mid April to the end of October. Harvest must be completed, generally, no later than one month after ice formation. Because the fish are not expected to overwinter the fishery has been labelled as a form of "put-and-take" fishery.

(2) The fishery makes use of the available natural food in the form of aquatic insect larvae and aquatic crustaceans such as Daphnia and Amphipoda (freshwater shrimp) which vary in numbers and species proportions between water bodies, within and between seasons. The stocking density is, therefore, limited by available food supply, a factor which can not be predicted or easily monitored.

(3) The water bodies being stocked are shallow with maximum depth of less than 7 m. Those in the agricultural belt are generally nutrient rich. The combination of shallow depth and high nutrients promotes dense growths of noxious blue-green algae during periods of elevated mid summer temperatures. Collapse of these populations often results in summer fish kills from dissolved oxygen depletion.

(4) Shallow trout ponds often develop dense growths of aquatic plants, algae and fungi, some of which instill an objectionable flavour in the fish flesh.

(5) In order to maximize the season's growth potential, harvesting of trout is delayed to near freezeup or shortly after freezeup. The cold temperatures, lack of experience and appropriate equipment on the part of the fishermen, and insufficient effort combine to provide a generally poor harvest with a potential for flooding the market if significant production were ever achieved.

The objectives of these studies are to develop strategies which would:

(1) Maximize the use of conveniently available water resources for aquaculture.

(2) Realize maximum growth rates for the largest number of fish possible.

(3) Maximize harvest recoveries of stocked fish.

(4) Maximize the use of natural food for growth supplements and flesh colour enhancement.

(5) Provide control over fish quality, size to meet market demand and time of harvest.

(6) Identify risks associated with various pond culture strategies.

In order to achieve the stated objectives, the Saskatchewan Research Council has entered into an ongoing research program on the suitability of cage culture for rainbow trout in simulated farm dugout conditions.

Specific study objectives of the first year of research included:

(1) Demonstration that cage culture of rainbow trout in a pond

typical of a farm dugout is practical at a stocking density 15 times that sustainable for free ranging fish living on natural food.

(2) Measurement of growth rates on artificial diets vs artificial diets supplemented by terrestrial insects attracted by lights.

(3) Observations of response of a closed pond system to high nutrient enrichment resulting from intensive fish culture.

Secondary objectives included experimentation with feeder and aerator designs suitable for Saskatchewan pond rearing conditions.

The study was continued in its second year to:

(1) Determine the effect on a pond of successive intensive pond culture programs.

(2) Determine the maximum permissible stocking densities and to identify and rectify stress conditions.

(3) Determine the effects of lights on fish growth.

(4) Determine the value of artificially pigmented feeds in the enhancement of fish flesh colour.

(5) Induce flesh colour through natural food supplements.

(6) Determine the feasibility of developing and maintaining brood stocks of rainbow trout under pond culture conditions.

3 METHODS

3.1 The Study Area

The Saskatchewan Research Council owns three lined ponds in its research and storage compound within the limits of the City of Saskatoon. Two of the ponds were designed to conform to the dimensions of a typical farm dugout for water storage (Figure 1). Dimensions of each are 20 x 50 m with an operating depth of 3.4 m. Operating volume of each pond is approximately 150×10^4 litres. The third pond is large and shallow (approximately 1 m deep) and was used to grow and maintain live food for the fish culture ponds. The fish culture ponds have a near vertical slope along their length and are more gradually sloped (approximately 45°) at the ends (Figure 2). The ponds are lined with a butyl rubber membrane and were originally filled with dechlorinated water from the City of Saskatoon water supply. Surface runoff from a large storage compound contributes significantly to one (East) pond. In the course of the experiments some topping up with dechlorinated city water was necessary to compensate for evaporative losses and leakage through the pond liners particularly in the West pond. Dechlorination was achieved by the use of hydrated and anhydrous sodium thiosulphate in solution. In May and for periodic topping up of ponds throughout the open water season, a sodium thiosulphate solution (4.74 M, 750 g/L) was injected in the water supply line at the rate of 29.7 ppm.

The ponds have not been drained for approximately ten years and have accumulated a layer of sediment originating from windblown dust, surface runoff and decaying plankton and macrophytes. They support an assemblage of invertebrate fauna such as Gammarus, damselfly larvae, water beetles,

Figure 1. One of the ponds used for aquaculture studies

Figure 2. Pond drawn down to show bottom configuration.

chironomid and mayfly larvae, corixids and snails characteristic of a prairie pothole. Macrophytes are sparse, being limited by the lack of shallow littoral areas. They consist of moderate growths of Myriophyllum at the more gently sloping ends of the ponds.

The ponds are ice free from mid April to the end of October (approximately 200 days). Maximum mid summer water temperatures range up to 23°C.

3.2 Culture Facilities

3.2.1 Cages

Rainbow trout were cultured in cages constructed of 0.64 cm (¼ in.) ace oval white nylon netting. The cages were cylindrical with a diameter of 2.44 m (8 ft.) and a depth of 1.8 m (6 ft.) for a total cage volume of 8.54 m^3. The netting was hung on a ring of 5 cm. ABS plastic pipe which doubled as a flotation device (Figure 3). A ring of #3 size (9 mm) wire helped shape the bottom of the net and provided an attachment for the floor of the cage, also constructed of 0.64 cm ace oval netting. A skirt of netting equipped with a drawstring extended over a hooped superstructure above the water surface to prevent fish from escaping and predators from entering the cages. Floating within the cage was a platform (5 x 80 x 80 cm) made from extruded styrofoam sandwiched between two sheets of 7.5 mm plywood. In the center was a hole 30 cm in diameter through which food would drop. A series of aluminum struts were fastened to the top of the platform to supply support for the feeder system. This platform also provided shade for the fish.

In the second year the superstructure was changed to 2 x 4 and

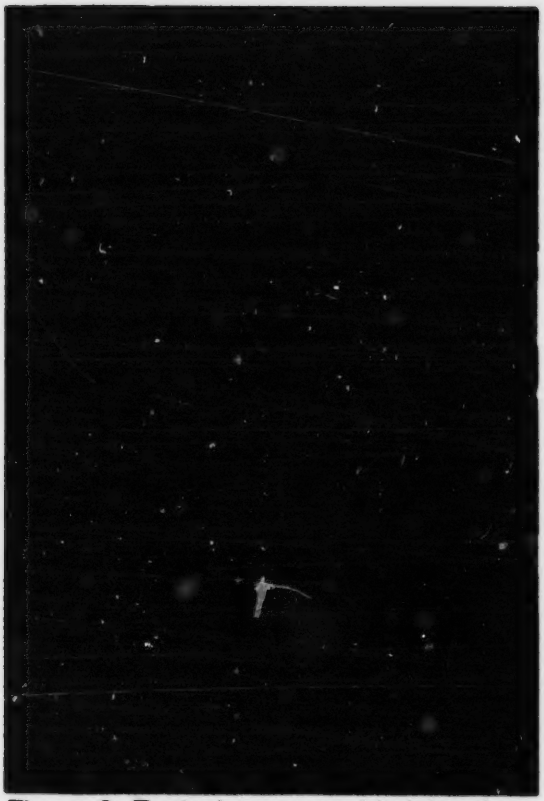

Figure 3. Typical cage used in intensive fish culture experiments.

Figure 4. Demand feeder used in early phase of the study.

mounted on the top of the flotation collar of the cage. A section of plywood was installed on the south facing panel. The feeders and lights were mounted on this structure replacing the need for the previously used floating platform. The platform provided support for feeders, lights and light traps.

3.2.2 Feed and Feeders

Caged fish were fed with pelletized artificial fish feeds. Initially conical demand feeders of the type shown in Figure 4 were used. Differences in fish responses to the feeders coupled with problems in design which caused plugging and bridging resulted in modification of the feeders to an automated design. Motor driven augering devices were installed in the throat of the demand feeders. These were activated by a commercially available timer to dispense a prescribed amount of feed twice a day.

In the second year a new timer design was introduced. This timer was activated and deactivated by a photocell. When the timer is on it can be programmed to dispense feed at regular periods ranging from 1 second to 256 seconds.

Following the change to automated feeding, feeding rates were calculated on the basis of water temperature, weight and numbers of fish in each cage. In the first season the fish were fed at a rate prescribed by the feed supplier and their parent company Rangen Feeds (see Table 2). The rates were adjusted approximately once a month to accommodate in-

Table 2. Rangen Feeding Formula, Percent of Body Weight for Daily Feed.

Count per kg	Rec. Feed Size	Water Temperature (°C)						
		4.4 - 7.2	7.7 - 8.8	9.4 - 10.5	11.1 - 12.2	12.7 - 13.8	14.4 - 15.5	16.1 - 17.2
2640	Fry 2	4.1	4.5	4.8	5.1	5.9	6.5	6.9
1320	Fry 3	4.0	4.2	4.7	5.0	5.8	6.0	6.3
660	Fry 3	3.9	4.1	4.6	4.9	5.4	5.7	5.9
440	Fry 4	3.6	4.0	4.5	4.8	5.0	5.1	5.3
220	Fry 4	3.2	3.8	4.2	4.5	4.6	4.7	5.0
176	5 Fingerling	3.0	3.4	3.9	4.2	4.4	4.6	4.7
132	5 Fingerling	2.9	3.2	3.7	3.8	3.9	4.0	4.3
88	5 Fingerling	2.7	2.9	3.3	3.4	3.5	3.6	3.9
66	5/32 Crumbles	2.0	2.5	3.0	3.1	3.2	3.4	3.7
44	5/32 Crumbles	1.9	2.2	2.6	2.8	2.9	3.0	3.3
33	5/32 Crumbles	1.7	2.0	2.4	2.5	2.6	2.7	3.0
26.4	5/32 Crumbles	1.6	1.9	2.1	2.3	2.4	2.5	2.8
19.8	5/32 Cut Short	1.5	1.8	2.0	2.2	2.3	2.4	2.7
15.4	5/32 Cut Short	1.4	1.7	1.8	2.1	2.2	2.3	2.6
13.2	5/32 Cut Short	1.3	1.6	1.7	2.0	2.1	2.2	2.5
11.0	5/32 Cut Short	1.2	1.5	1.6	1.8	1.9	2.0	2.3
8.8	5/32 Cut Short	1.1	1.4	1.5	1.7	1.8	1.9	2.2
6.6	5/32 Cut Short	1.0	1.3	1.4	1.6	1.7	1.8	2.0
4.4	5/32 Cut Short	0.9	1.2	1.3	1.5	1.6	1.7	1.8
2.2	5/32 Cut Short	0.9	1.0	1.2	1.3	1.4	1.5	1.6

From Rangen Feeds, Buehl, Idaho.

creases in weight of fish. The prescribed daily food ration was dispensed over two feeding periods. Record of total amounts of feed used and total biomass of fish produced in each cage was maintained for use in the calculation of a final feed conversion ratio.

In the second year, feeding rates were calculated on the basis of a projected conversion rate of 1.24:1 dry feed to wet body weight using the formula (Piper et al., 1982).

$$\frac{C \times 3 \times \Delta L \times 100}{L} = \text{daily feed ration as \% of body wt (lbs)}$$

C = conversion factor to be achieved (1.24 in our experiments)

ΔL = daily length increase in inches

L = length in inches at weighing

% of body wt x total fish weight = feed ration per day

The calculated feeding rates ranged from 1.8 to 3% of total fish weight per day. Feeding rates were adjusted about once per month to accommodate increases in fish size.

The trout feed was a commercial formulation developed by Rangen Feeds, Buehl, Idaho and supplied by M & H Feeds of Surrey, British Columbia. Feed formulations as provided by the manufacturer are given in Table 3. Three sizes of feed were used. Granular fingerling feed (No. 5) was provided for the first 30 days of the grow out period. The feed was then switched to 3/32 inch diameter extruded pellets and finally to 5/32 inch extruded pellets. In the latter part of 1982 and in 1983 experiments were conducted comparing artificially pigmented feeds with non

Table 3. Feed Formulations Used in Intensive Cage Culture Experiments[1].

	Formulated	Guaranteed
Trout Grower (#5 granular and 3/32 pellets)		
Protein, not less than	40%	38%
Fat, not less than	10%	9%
Fiber, not more than	3.5%	5%
Moisture	9%	--
Ash	11%	--
Trout Production (5/32 pellets)		
Protein, not less than	39%	38%
Fat, not less than	10%	9%
Fiber, not more than	4.5%	5%
Moisture	9%	--
Ash	12.5%	--

[1]From Rangen Inc. Buhl, Idaho.

coloured feeds in inducing development of pink flesh in trout. A maintenance formulation of colouring agent cantaxanthin, a bacteriologically produced pigment, was incorporated in the pellets by the feed manufacturer.

The artificial fish diet was supplemented by a natural population of invertebrate larvae and adults living in the ponds as well as by nocturnal adult insects attracted to the cages by lights.

3.3 Fish Stocks

Rainbow trout fingerlings used in our experiments were obtained from two sources. In 1982, fingerlings were obtained from The Aquaculture Centre, a local trout hatchery. The fingerlings were of the Mount Lassen strain grown from eggs obtained from Mount Lassen Trout Farms, Red Bluff, California. The fingerlings were graded to 10 ± 0.6 cm. In 1983 fingerlings were not available from the above supplier. Fingerlings were obtained from North Saskatchewan Trout Farmers' Association who imports fingerlings from Trout Springs Hatchery, Buffalo Gap, South Dakota for distribution among its members. The fingerlings were of a strain descendent from Mount Lassen stocks. This could not be verified. The fingerling were purchased as 10 cm stock but had a mean length of only 9 cm in the first lot and 8.4 cm in the second.

3.4 Aeration

Aeration was required to enhance nighttime dissolved oxygen levels during the summer. Spray aerators were constructed following the design of miniature models demonstrated in European aquaculture systems. Slot-

ted 10 cm diameter plastic pipe was equipped with a double impeller vertical shaft driven by a 1/3 HP electric motor (Figure 5). Water drawn in through slots of the partly submerged aerator pipe is sprayed out through slots approximately 40 cm above the surface at a rate of 530 L/min (Figure 6). Oxygen is replenished by diffusion in the spray and turbulence created by the pump.

Summer time aeration was carried out at night in order to reduce heat uptake and to enhance nighttime cooling of the pond.

3.5 The Experimental Program - Year One

In the first year of aquaculture research undertaken by the Saskatchewan Research Council only one pond was used to demonstrate the feasibility of intensive cage culturing of rainbow trout. Two 2.45 m diameter cages were installed. Each cage was stocked on June 2 with approximately 750 fish. The stocking density for the pond was estimated to be 15 times that which could be supported on a natural invertebrate diet in a typical farm dugout.

Both cages were equipped with demand feeders which were floated inside the cage on a styrofoam pad. These were later automated to dispense feed twice per day. Feeding rate was determined as a percentage of body weight per day adjusted for water temperature and type of feed according to tables provided by Rangen as described earlier (Table 2). Rates were adjusted at approximately one month intervals to accommodate changes in body weight. Records of total amounts of feed provided to each cage

Figure 5. Spray aerator used to enhance dissolved oxygen levels.

Figure 6. Spray aerator in operation.

were kept.

One cage (cage A) was maintained as a control. The second (cage B) was equipped with a commercial light trap to provide night flying terrestrial insects as a feed supplement and to determine whether continuous light had any effect on growth rate of the fish. A second light trap was placed approximately 30 m away to collect and monitor available insects.

Fish were maintained under culture conditions from June 2 until November 3 just prior to freezeup, a total of 153 days. All but 100 fish were harvested and sold. Of the 100 fish, 75 were placed in a cage for overwintering without further feeding. Twenty-five were released into the pond to forage on natural stocks of invertebrates. The overwintering of rainbow trout will be discussed in a separate report.

During the summer months the pond was aerated with one diffuser from dusk to dawn to maintain dissolved oxygen levels and to suppress pond temperatures.

Monitoring of the first year of operations included:

(1) Weighing samples of fish at approximately one month intervals to establish growth rates.

(2) Records of artificial feed provided to determine feed conversions.

(3) Measurements of insect fauna attracted by light traps.

(4) Measurement of surface water temperature at least once every two days during the open water period.

(5) Measurement of dissolved oxygen approximately once every two weeks from near the end of July through to the end of October.

3.6 The Experimental Program - Year Two

The research program was expanded in the second year in response to the successes and conclusions derived from the first year of operations. The first year experiment was repeated to determine whether a closed system could sustain an intensive aquaculture program for more than one year. In addition a third cage was installed to hold 77 fish which survived the first year.

The second pond, the west pond, which had never been stocked previously, was topped up with city water and equipped with four cages to determine whether it could sustain a population of 3000 trout, double the density of the previous year's stocking and approximately 30 times the population the pond could sustain on natural food.

Stocking of the cages was carried out on May 4 with an estimated 750 fingerlings per cage. The presence of residual chlorine in the freshly topped up west pond resulted in the loss of all fingerlings in the four cages in the first 24 hours. The pond was dechlorinated with sodium thiosulphate and restocked on May 16 with another 3000 fingerlings obtained from the same source.

The overwintered fish from the previous year's experiments were recaptured and placed in a cage.

Automatic feeders, equipped with photo cells, were operative from dawn to dusk beginning on May 27. Each was programmed to dispense feed every two hours at a rate which would provide a prescribed daily ration. The ration for each cage was calculated using the Piper formula described earlier.

The amount of feed was adjusted as new growth data became available,

approximately once per month. As in the first year of operation, records were maintained of total amounts of feed provided to each cage.

Both coloured and noncoloured feeds were used to determine whether artificial pigments could impart a pink colour in the fish flesh. One half of the cages in each pond were provided coloured feed. Similarly, one half of the cages were provided light from dusk to dawn by means of a 150 W flood lamp. The purpose of the latter was to attract terrestrial insects to the cages for nighttime feeding. The combination of lights and coloured feed is shown in Figure 7.

Fish which survived the experimental conditions were selectively harvested October 19 to 21. Only those trout which approached 200 g in total weight were processed. The remainder (365) were prepared for overwintering.

Aeration was carried out throughout the grow-out period in the second summer. Two aerators were operated in the east pond which had trout for its second year. One aerator was installed in the west pond. The aerators were operated from dusk to dawn through to mid September to maintain dissolved oxygen levels and to suppress pond temperatures. After mid September the aerators were operated during the day to increase daytime temperatures and to prevent abnormal nighttime cooling.

Monitoring of the second year of operations included:

(1) Daily inspection of feeders, aerators and lights.

(2) Measurement of dissolved oxygen three times a week.

(3) Measurement of pH, specific conductivity and Secchi disc transparency once a week.

(4) Fish weighed every 2 weeks - 50 fish per cage.

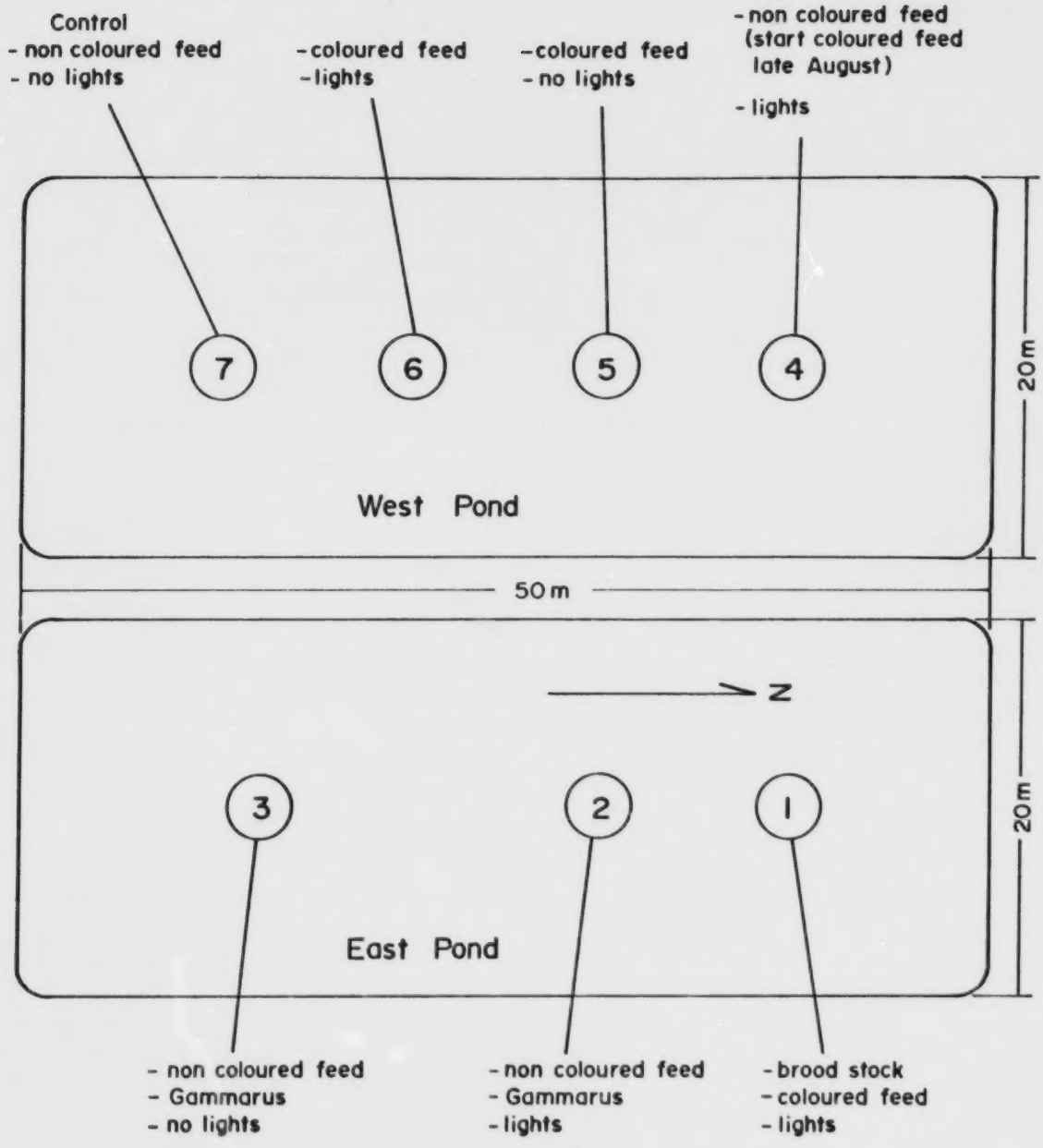

Figure 7. Diagram of cage locations, feed and light combinations.

(5) Fish lengths once per month - approximately 50 per cage.

(6) Ammonia measurements four times during the summer.

4 RESULTS

4.1 Summer Program - Year One

4.1.1 Stocking Density

The fish stocking began on June 2, 1982, about one month later than stocking is normally undertaken for "prairie" pond culture operations. The fish at the time of stocking averaged 14 cm (5.5 in.) in length. The fish in the control cage (cage A) had a mean weight of 41.7 g (n = 68). Fifty fish in cage B had a mean weight of 50.6 g.

Seven hundred and fifty fish (estimated on weight basis) were intended to be stocked in each cage. The actual stocking rates, based on numbers of fish harvested, were 836 in cage A and 680 in cage B. The stocking density based on these final numbers was 97.9/m^3 and 79.6/m^3 of cage volume in cages A and B, respectively. These represented 4.08 kg/m^3 and 4.03 kg/m^3 by final weight. The stocking densities based on final harvest do not include mortality and specimens sacrificed for quality evaluation during the experiment. One dead fish was removed from cage A and 12 from cage B during the summer. In addition 16 fish were taken from cage A and 15 from cage B for evaluation of flesh colour and taste.

4.1.2 Feeding

One demand feeder was installed in each of the cages. The fish were initially fed Rangen's No. 5 Fingerling feed at a daily rate based on a percentage of body weight and adjusted for temperature according to the chart provided in Table 2. The rate was adjusted approximately once per month following the weighing of a representative sample of fish. The feed formulation was changed to 3/32 extruded sinking feed on July 15 and

to 5/32 extruded feed in September.

In order to insure that the fish were receiving their daily ration of feed, the feeders were checked daily and the fish hand fed when the feeders were apparently not working. The demand feeders were a constant source of problems resulting from bridging and plugging with fines to plugging with moist and clumped feed. Automatic feed dispensing devices were installed in September 23, 1982, to complete the season. The total quantity of feed used in cage A was 242.9 kg (298 g/fish). Cage B was fed 239.3 kg (352 g/fish).

On June 17, cage B was equipped with an insect trap to attract adult insects as supplementary food for the fish. The trap was equipped with a timer to allow the lights to come on at 8:00 pm and go off at 6:00 am. The lights provided were three ultraviolet flourescent tubes each about 15 cm in length. A second similar light trap equipped with a collecting bag, was installed approximately 50 m away to monitor numbers and variety of insects attracted. On July 5 both traps were equipped with 150 watt incandescent flood lamps to help improve their efficiency. The flood lamp served a second purpose in providing fish with light 24 hours per day.

A total of 320 g (dry weight) of flying insects was caught in the control insect trap. The quantity of biomass (5.00 g/day for 64 days) is insignificant when compared with the total food intake of the fish. However, the insects may provide essential trace elements or amino acids which are not available in the artificial feed. These trace constituents may serve to improve the appetite of the fish or digestability of artificial food.

4.1.3 Fish Growth and Feed Conversion

Fish growth measurements were made six times during the growing season at approximately one month intervals (Figure 8). Total weights were obtained from about 50 fish on each occasion. Individual fork lengths were obtained on two occasions, August 5 and September 7. For this purpose the fish were anaesthetized with tricaine methanesulphonate (MS222) (0.1-0.2 g/L for 5-10 min. for 10-25 cm fish). Fish were not measured during periods of high summer temperatures to avoid subjecting them to undue stress as a result of handling.

Fish in the control cage A increased from a mean of 41.7 g to 205 g over a period of 145 days for an average of 1.13 g per day (Figure 8). The fish in the experimental cage (B) grew from 50.6 g to 255.6 g over the same period for an average increase of 1.41 g per day.

Fish lengths at the time of stocking were estimated at 14 cm. Changes in length (cm) during the season are shown below.

	Cage A		Cage B	
	Mean Length	Range	Mean Length	Range
August 5	17.7	15.6-18.9	19.4	16.8-21.4
September 7	20.8	19.1-22.0	22.8	20.1-23.2
November 3	25.0	22.5-26.7	26.2	22.0-29.2

Feed conversion rates were calculated on the basis of total fish weights and total weights of food consumed during the season. The control cage was fed 236.9 kg of feed to produce 139.7 kg of fish biomass (Total weight - 41.7 kg initial fingerling weight) for a net conversion factor of 1.70. The experimental cage was fed 231.3 kg of feed to produce 121.7 kg of fish biomass (Total weight - 50.6 kg initial fingerling weight) for a net conversion factor of 1.90.

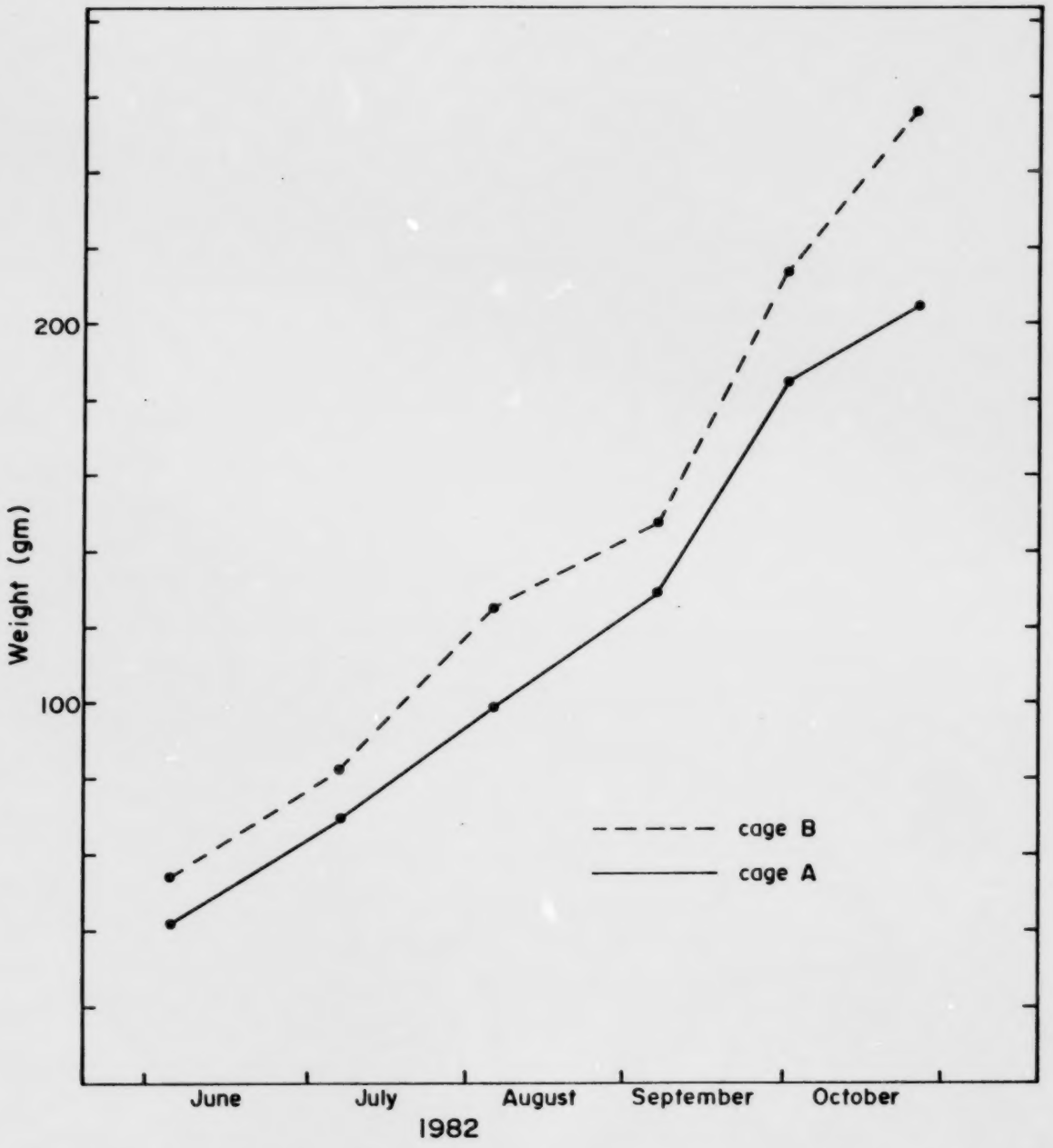

Figure 8. Growth rates of rainbow trout cultured in experimental cages in 1982.

Cumulative and incremental feed conversions following each weighing are shown in Tables 4 and 5.

4.1.4 Fish Harvest

A total of 836 fish were harvested from the control cage for a net dressed weight (head on) of 142.3 kg (313.75 lb) averaging 170.2 g per fish. Five hundred and eight-one fish were harvested from cage B, the experimental cage. A net dressed weight of 130.6 kg (288 lb.), averaging 224.8 g per fish was achieved. An additional 100 fish weighing an estimated 22.5 kg were spared for overwintering experiments. An average of 20% of total fish weight was discarded as waste.

4.1.5 Summer Fish Mortality

Fish mortality was monitored during the course of the study. Only one dead fish was taken from the control cage during the entire summer. An unknown but small number was caught by a mink which visited the cages for two nights. The losses from the experimental cage were higher. Fourteen dead fish were recovered at a rate of approximately one per week beginning June 17. No specific cause could be attributed to the mortality although stress factors such as crowding, handling and depressed oxygen levels are believed to play a significant role. Some dorsal fin erosion and other physical abnormalities were noted in the early mortalities. The mortalities in the experimental cage represent 2% of the total fish stocked and 0.1% in the control cage.

Table 4. Cumulative Feed Conversion Ratios, 1982.

	Conversion Factor	
Period	Cage A	Cage B
June 3 to July 6	2.53	0.99
June 3 to August 5	2.11	2.23
June 3 to September 7	2.47	2.09
June 3 to October 25	1.90	1.70

Table 5. Incremental Feed Conversion Ratios, 1982.

	Conversion Factor	
Period	Cage A	Cage B
June 3 to July 6	2.53	0.99
July 7 to August 5	1.77	2.48
August 5 to September 7	3.63	1.83
September 7 to October 25	1.39	1.25

4.1.6 Summer Pond Management

Pond temperatures were measured twice daily for most of the month of June and then approximately once daily through to mid September (Appendix 1). The June measurements showed diurnal fluctuations of 0.5 to 1.5°C from early morning minima to afternoon maxima. Temperatures increased gradually during June from about 15°C at the beginning of the study to 20°C at the end of the month. Temperatures averaged 20.3°C in July and August. By mid September when measurements ceased temperatures were dropping rapidly. Maximum temperatures of 22°C were reported on August 1.

Dissolved oxygen measurements were taken less frequently beginning on June 25 as water temperatures exceeded 20°C. Initially only surface measurements were reported. Later in the season complete profiles were taken when it became apparent that an oxygen gradient was developing. Measurements were made both inside and outside the cages. Because the cage depth interfers with measurement of profiles only those values taken outside the cages are reported. Generally the measurements inside the cage were up to 0.7 mg/L lower than outside the cage.

Dissolved oxygen levels near the surface dropped with increasing summer temperatures and generally hovered in the 6.0 to 7.5 range from July 1 to mid September (Appendix 2). A diffuser aerator was installed on July 13 and operated during the night to help maintain oxygen levels. Lowest surface levels of 5.3 mg/L were reported on August 15, two days following mechanical problems with the aerator. In profile, dissolved oxygen levels were generally suppressed below the 2 m level reaching almost total anoxia at the sediment interface.

No measurements of parameters such as ammonia, nitrite or nitrate were undertaken in 1982. No plankton measurement or control was undertaken. Secchi disc transparency measurements were made from mid July to mid September. Lowest transparency levels of 0.9 m indicating heaviest plankton crop were reported during mid July (Table 6). Transparency improved from this point to provide light penetration to the bottom of the pond by August 11. Very low plankton populations provided total light penetration for the entire month following. There was some indication of a trend to lower transparency when measurements ceased on September 1.

The trout pond was topped with water on June 25-28 to compensate for leakage and evaporative losses. Water depth was increased by about 33 cm with water pumped from the adjacent dugout.

4.2 Summer Program - Year Two

4.2.1 Stocking Density

The success of the first year of aquaculture research guided the planning of the stocking density for the second year's program. Two questions were posed: (1) could a closed pond the size of a farm dugout sustain a high stocking density in successive years? (2) What is the optimum pond stocking rate for a farm dugout under cage culture conditions?

To answer the first question a stocking rate similar to the first year was planned for the experimental pond (henceforth referred to as East pond), i.e. two cages with 750 fish in each. In addition a third cage contained fish captured from the previous year's overwintering as part of a brood stock development program. Two experimental cages (#2 and #3) were stocked on May 4 with 7.26 and 7.72 kg of fish, respectively.

Table 6. Secchi Disc Transparency, 1982.

Date	Depth (m)
July 16	0.9
July 17	0.9
July 19	0.9
July 22	1.1
July 24	1.4
July 27	1.8
July 30	1.9
July 31	2.3
August 1	2.3
August 4	2.9
August 11	3+
August 12	3.1
August 18	3.2
August 31	3.2 (bottom)
September 6	3.2 (bottom)
September 8	3.1
September 10	2.8

At an average number of 97 fish per kilogram the stocking rate was estimated at 704 and 749 fish, respectively. Actual numbers based on final counts at harvest and adjusted for mortality and subsampling were 632 and 587 fish in cages #2 and #3.

Stocking density based on these numbers was 74.0 and 68.7 fish/m^3 per cage. Based on initial weights, the stocking density was 0.85 kg/m^3 in cage #2 and 0.90 kg/m^3 in cage #3. On the basis of harvested weights the stocking density in cage #2 was 13.7 kg/m^3. A large number of the fish stocked in cage #3 escaped through a hole in the mesh shortly after stocking. An abnormally low level of activity was noted as early as May 19, two weeks after stocking. The hole was discovered and repaired on June 8. At that time a total of 240 fish were counted. The remainder had escaped into the pond. Shortly before harvest another 110 escaped through a new hole leaving only 130 in the cage. The initial stocking density in cage #3 included 448 fish retrieved from the pond by seining at the end of the season. A summer stocking density of 240 fish or 28.1/m^3 of cage volume is assumed.

Cage #1 was stocked with yearling trout which had overwintered in the pond plus others of the same stock which were donated at the end of some laboratory experiments. Fifty-two fish weighing an average of 288.6 g each (total weight 15.01 kg) were recovered by seining. Seven fish weighing an average of 137.9 g were added from an experimental cage which had overwintered in the pond. In addition 18 fish, also of the same stock, were donated. These weighed 1.8 kg or 100.8 g/fish. Numbers of overwintered "brood stock" totalled 77 with an overall average weight of 230.8 g. Stocking density of brood stock was 9.02 fish/m^3 or

2.08 kg/m^3.

The initial stocking density for the pond including all fish was estimated at 0.86 fish/m^3 of pond volume.

In an attempt to determine the optimum pond stocking rate for a farm dugout under cage culture conditions a second adjacent (west) pond, previously not stocked, was activated. The pond was topped with the City of Saskatoon tap water over a period of four days beginning six days before stocking. Four cages were installed. On May 4 each of these was stocked with 7.7 kg of fish representing 750 specimens. All fish in all four cages were dead the following day as a result of residual chlorine introduced in the city top up water demonstrating that one must not rely on passive dissipation of chlorine into the atmosphere as a means of dechlorinating water for fish culture.

The west pond was treated with sodium thiosulphate to remove the chlorine. The cages were restocked on May 16 following in situ toxicity bioassays with fish from the east pond. The cages were restocked with 7.08 kg of fish (estimated at 105.76 fish/kg) per cage. The fish density based on final fish counts was as follows:

Cage No.	4	5	6	7
Number of fish	909	907	836	774
No./m^3 of cage volume	106.4	106.2	97.9	90.6

An additional 19 fish were recovered from the pond outside the cages. The pond stocking density, assuming a pond volume of 1500 m^3, was 2.27 fish/m^3, approximately 2.6 times the density of the adjacent east pond.

All fish died on September 2 as a result of severe dissolved oxygen depletion. At that time the cage stocking densities on a whole weight basis were estimated as follows:

Cage No.	4	5	6	7
Total fish weight (kg)	73.03	85.68	87.68	78.90
Wt. kg/m^3 of cage volume	8.55	10.03	10.25	9.24

The pond stocking density based on total fish weight at the end of the experiment was 218 g/m^3.

4.2.2 Feeding

All cages were equipped with automatic feeders designed and manufactured by the Saskatchewan Research Council (see Section 3 for feeds and feeding rates). Feed formulations were similar to those used in the first year of experiments. The trout were started on crumbles (No. 5) then were switched to 3/32 and 5/32 extruded pellets as they increased in size. Pigmented feed coloured with a maintenance level of canthaxanthin was fed to the fish in cages #1 (brood stock), #5 and #6 in order to introduce a pink colour in the flesh. The plan to supplement the diet of cage #2 with Gammarus was abandoned when attempts to maintain Gammarus stocks failed. As a result cage #2 was also placed on a maintenance level of canthaxanthin.

A careful record was maintained of weights of feed provided to each cage. Persistent problems with timers and dispensing mechanisms in the feeders required daily inspection and testing to insure that the feeders were operating. The main problem was related to the presence of an excessive proportion of fines in the feed which caused bridging in the throats of the feeders. The timers, originally designed to dispense feed every two hours, were found to be dispensing feed every hour. This malfunction was discovered through a check of the function of individual timers. The malfunction was then traced back to at least as early as

the beginning of July through the quantities of feed used. The combination of feeder malfunction due to poor feed and timer malfunction has resulted in difficulties in optimizing growth rates and feed conversion, and evaluating other variables such as provision of lights and light attracted insects. A further complicating factor is the variability in actual stocking rates (generally overstocking) because of the small size and variability of fingerlings while basing feeding rates on 750 fish per cage.

4.2.3 Fish Growth and Feed Conversion

Representative subsamples of fish in cages #2 to #7 were measured for individual length and weight four times during the growing season (May 18, June 6, July 4 and July 26). To avoid undue stress during very hot periods of the summer, mass fish weights based on 50 fish from each cage were taken on July 18 and August 11 only.

In addition fish weights are available for cages #2 and #3 on May 5. Lengths and weights were taken on September 14 and at harvest time on October 21. Samples of fish from cages #4 to #7 were retained for length and weight measurements following the total fish kill in these cages on September 2.

A summary of length and weight gains is provided in Table 7. Growth rates based on weight data are shown in Figures 9, 10 and 11. Growth curves derived for the complete growing season in cages #2 and #3 showed evidence of a sigmoid curve. Fingerlings increased in weight slowly during the first month. Growth rate increased to a maximum from about mid July to mid September then showed signs of levelling off during October.

Table 7. Summary of Lengths (cm) and Weights (g) of Cage Cultured Rainbow Trout, 1983.

Date		Cage 2	3	4	5	6	7
May 5	weight	11.2	9.7	--	--	--	--
May 18	weight	15.75	15.0	7.73	9.6	9.9	9.0
	length	93.08	93.22	84.6	84.08	85.66	84.9
	length range	63-112	53-113	61-117	65-108	65-114	66-110
June 6-8	weight	23.4	29.1	12.0	13.4	13.9	14.8
	length	120.86	121.8	99.6	96.2	102.4	102.6
	length range	98-142	74-148	78-138	64-121	77-118	69-135
July 4	weight	46.0	63.4	35.4	28.0	30.6	30.0
	length	140.9	151.7	116.1	120.2	123.3	122.0
	length range	84-172	95-181	98-139	98-179	91-151	89-158
July 18	weight	58.1	86.5	32.6	39.6	46.0	48.6
July 26	weight	73.3	99.3	44.5	49.7	38.3	63.8
	length	167.1	183.0	138.4	148.8	151.6	150.4
	length range	120-198	136-220	113-158	128-176	120-180	105-175
August 11	weight	91.3	131.8	65.1	76.7	84.2	76.0
September 2-6	weight	--	--	79.6	92.4	100.7	107.5
	length	--	--	166.2	168.5	175.4	181.4
	length range						
September 14	weight	144.6	277.6				
	length	200.6	225				
	length range	118-255	178-272				
October 21	weight	183.78	290.1				
	length	223.3	25.9				
	length range	11.7-26.8	19.8-29.5				

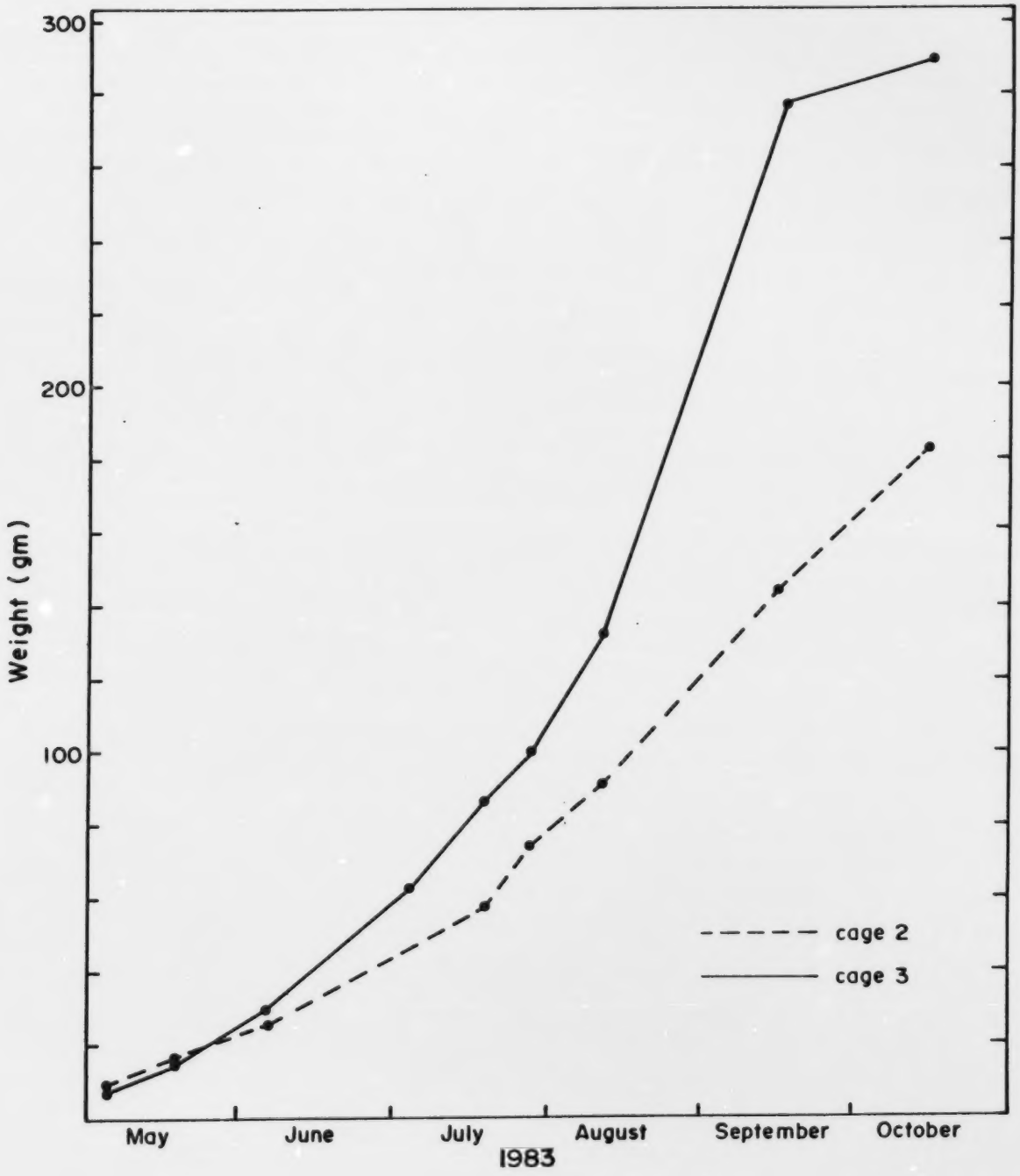

Figure 9. Growth rates of rainbow trout in experimental cages, east pond, 1983.

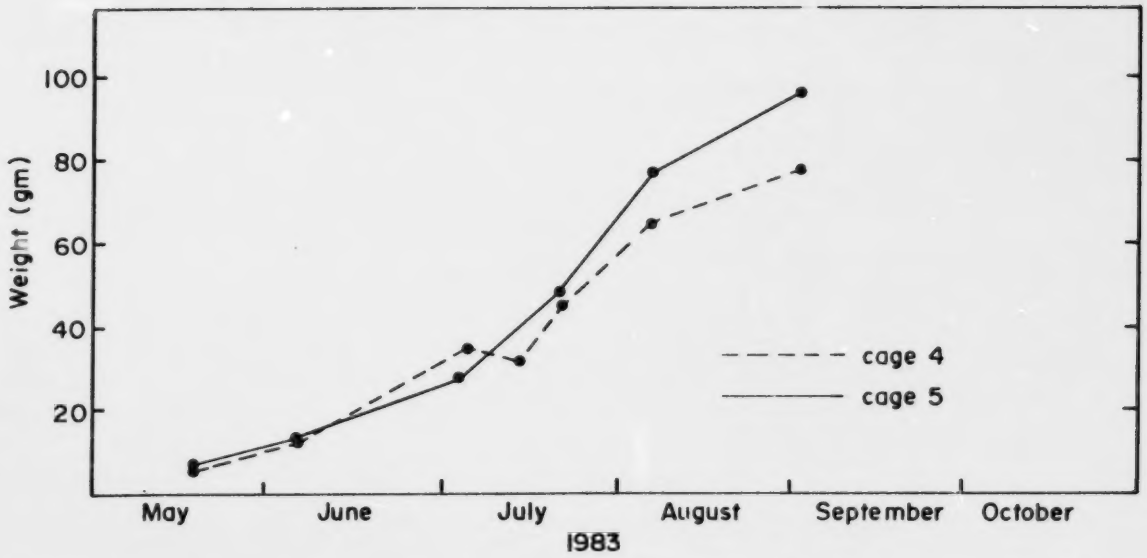

Figure 10. Growth rates of rainbow trout in experimental cages 4 and 5, west pond, 1983.

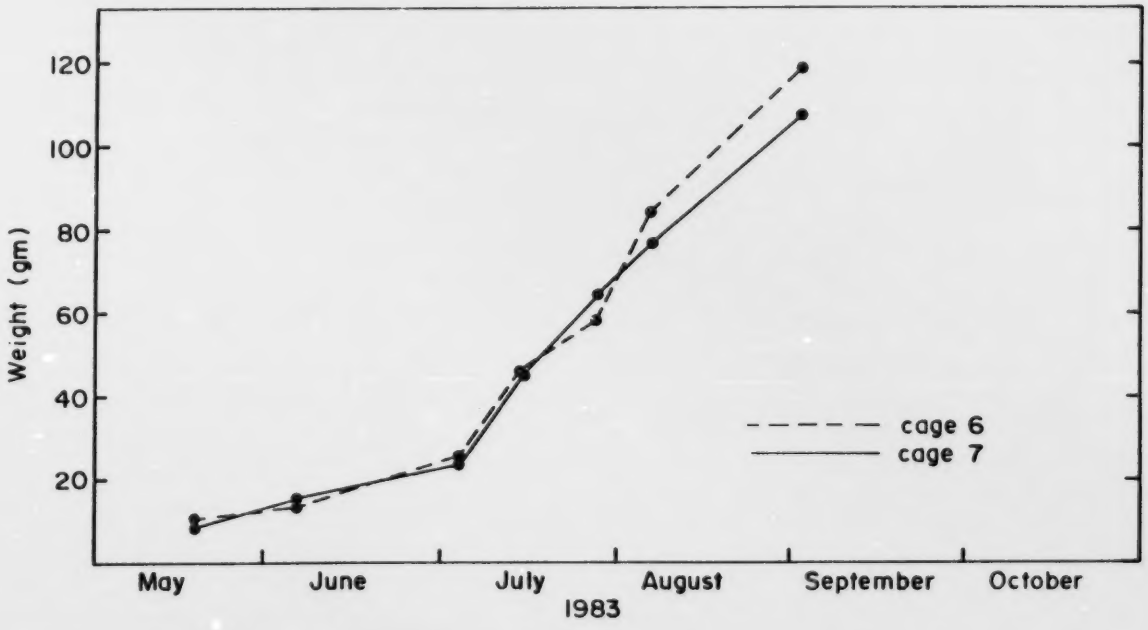

Figure 11. Growth rates of rainbow trout in experimental cages 6 and 7, west pond, 1983.

The growth rate in cage #2 was similar to that experienced in the two cages in 1982. Fish in cage #3 showed the highest rate of weight gain and the highest average weight achieved at harvest. This factor is attributed to the difference in stocking density as a result of the escape of two-thirds of the fish early in the growing season.

Growth curves for fish reared in cages #4 to #7 in the densely stocked pond were similar from the time of stocking to the first week in July. After this time, until the period of summer kill growth in cages #4 and #5 appeared somewhat slower than in cages #6 and #7. The average fish weights on September 2 were 79.6 and 92.4 g in cages #4 and #5 as compared with 100.7 and 107.5 g in cages #6 and #7, respectively.

The growth rates of fish in cages #5, #6 and #7 were similar to the growth rate of fish in cage #2. The differences in final weight were attributed to the later stocking date and the smaller size of fish at stocking in cages #4 to #7. The growth rate of fish in cage #4 was slightly lower than in cage #2. Some relationship exists between daily changes in lengths and weights and the stocking densities (Tables 8 and 9).

The growth rates of fish that escaped from cage #3 and ranged freely in the pond feeding on aquatic invertebrates and excess feed under the cages could not be determined because of the unavailability of data during the summer. Length and weight data obtained at harvest are further confused by a second escape of fish from cage #3 shortly before harvest. Fish recovered by seining averaged 176 g showing a considerably lower growth rate than in cage #3 (290.1 g). The lower ranges in lengths (13.8 cm) and weights (40 g) were lower than those cf the fish in cage #3.

Table 8. Growth Rates of Rainbow Trout in Length, 1983.

Cage #	No. of Fish	Initial Length (mm)	Final Length (mm)	Number of Days to Grow	Growth Rate (mm/day)
2	632	93.08	223.3	170	0.77
3	240	93.2	259.0	170	0.98
4	885	84.6	166.2	108	0.76
5	900	84.1	168.5	108	0.78
6	831	85.66	175.4	108	0.83
7	768	84.9	181.4	108	0.89

Table 9. Growth Rates of Rainbow Trout in Weight, 1983.

Cage #	No. of Fish	Initial Weight (g)	Final Weight (g)	Number of Days to Grow	Growth Rate (gm/day)
2	632	15.8	183.8	170	0.99
3	240	15.0	290.1	170	1.62
4	885	7.7	79.6	108	0.67
5	900	9.6	92.4	108	0.77
6	831	9.9	100.7	108	0.84
7	768	9.0	107.5	108	0.91

Similarly, the brood stock data obtained in 1983 are insufficient to develop a growth curve. Because of the extremely warm summer temperatures it was considered prudent to handle the fish as little as possible. In spite of this only 45 of the 77 fish survived. An additional four brood stock were recovered from the dugout by seining. The largest of the brood stock reared in the cage weighed 1105 g and measured 40.5 cm. The mean length (33.5 cm) and weight (652.1 g) of the caged fish was somewhat confused by the introduction of fish from three sources (and size groups) in the spring. The history of the fish and the numbers surviving from each group are no longer known. The largest fish in the cage showed an increase in length of 9.5 cm and in weight of 720 g over the largest fish stocked in the brood cage in the spring.

The four large fish that were recovered by seining had a mean length of 37.3 cm and a mean weight of 796 g.

Feed conversion values were calculated for each of the six cages carrying fish stocked in the spring. The feed conversion values are derived on the basis of total weights of feed provided and the total fish biomass less stocking weight calculated from samples weighed during the season and at harvest. To facilitate comparison, feed conversion factors were calculated for the period prior to each weighing to provide both cumulative and incremental values (Tables 10 and 11). The best overall feed conversion rate over the longest growing period was obtained in cage #3 (Table 10). Of the fish that succumbed to summer kill cage #7 (the control cage) showed the best growth performance with the highest mean weight gain and a feed conversion rate of 1.58.

Incremental feed conversion ratios were calculated for portions of

Table 10. Cumulative Feed Conversion Ratios, 1983.

Period	Conversion Factor					
	Cage 2	Cage 3	Cage 4	Cage 5	Cage 6	Cage 7
May 18 to June 6	1.24	1.82	0.97	1.20	1.19	0.91
May 18 to July 4	1.35	1.46	0.62	1.03	1.00	1.07
May 18 to July 18	1.94	1.49	1.49	1.35	1.08	1.06
May 18 to July 26	1.83	1.70	1.44	1.36	1.14	1.08
May 18 to August 11	2.11	1.65	1.38	1.25	1.21	1.51
May 18 to September 14	1.99	1.23	1.78*	1.65*	1.65*	1.58*
May 18 to October 21	1.99	1.76				

*May 18 to September 2

Table 11. Incremental Feed Conversion Ratios, 1983.

Period	Conversion Factor					
	Cage 2	Cage 3	Cage 4	Cage 5	Cage 6	Cage 7
May 18 to June 6	1.23	1.82	1.00	1.20	1.19	0.91
June 6 to July 4	1.38	1.31	0.55	0.99	0.95	1.13
July 4 to July 18	3.39	1.54	-6.967**	1.84	1.19	1.04
July 18 to July 26	1.51	2.89	1.35	1.40	1.30	1.14
July 26 to August 11	2.95	1.52	1.26	1.09	1.34	3.44
August 11 to September 14	1.77	0.89	3.34*	3.33*	3.66*	1.75*
September 14 to October 21	1.98	3.45				

*Period - August 11 to September 2

**Average weights of July 18 lower than July 4

the growing season between each weigh in for each cage (Table 11). Feed conversion rates ranged widely both within cages for different parts of the season and between cages during the same part of the season. The very low conversion rates of less than 1 may be indicative of underfeeding whereas high conversion ratios may be evidence of overfeeding and feed wasting.

Feeding rates based on a formula which assumed a feed conversion ratio of 1.25 were calculated for each period. These were compared with feed actually dispensed (Table 12) to provide some explanations for the variable conversion ratios. In the first two weigh in periods, May 18 to June 5 and June 6 to July 4, the amount of feed dispensed is roughly comparable to that calculated for the number of fish in the cages. The lower theoretical values for cages #2 and #3 in the second period reflect the fact that there were fewer fish in the cages than the feeders were set to feed. Considering the fact that cages #4 to #7 were overstocked the amount of feed actually dispensed to these cages was reasonably accurate. Between July 4 and midway through the August 11 to September 13 period all cages were overfed by a factor of 2. The magnitude of overfeeding of cages #4 to #7 is marked by the fact that the theoretical amount of feed is calculated on the basis of the actual number of fish in the cages at harvest which is higher than that assumed when the feeders were adjusted. The extensive overfeeding coupled with the fact that the feeders operated erratically as a result of bridging are factors which weigh heavily in the high and variable feed conversion factors achieved.

Certain incremental feed conversion data presented in Table 11 re-

Table 12. Feeding Rates for the Periods for which Conversion Rates were Calculated.

	May 18 to June 5	June 6 to July 4	July 4 to July 18	July 18 to July 25	July 26 to Aug. 10	Aug. 11 to Sept. 13	Sept. 14 to Oct. 21	Total (kg)
Cage #2								
Theoretical amount fed (g) *	5770	13649	11557	7151	17874	46485	83166	187.20
Grams/fish/day	0.487	0.782	1.329	1.439	1.816	2.227	3.564	
Actual amount fed (g)	5848	19409	25547	14228	32670	58070	47675	205.00
Grams/fish/day	0.494	1.113	2.938	2.864	3.320	2.782	2.043	
Cage #3								
Theoretical amount fed (g)	6478	6751	5643	4347	10030	25673	46368	107.44
Grams/fish/day	1.421	1.005	1.679	2.264	2.612	3.173	5.397	
Actual amount fed (g)	6142	10789	8589	8890	11830	31000	13772	98.51
Grams/fish/day	1.347	1.606	2.556	4.630	3.081	3.831	2.272	
Cage #4								
Theoretical amount fed (g)	4473	12549	16096	0597	18847	39043		99.86
Grams/fish/day	0.259	0.493	1.265	1.207	1.331	2.005		
Actual amount fed (g)	3682	11608	17733	14265	22923	42815		113.28
Grams/fish/day	0.213	0.456	1.393	1.962	1.619	2.199		
Cage #5								
Theoretical amount fed (g)	4852	13494	12623	9419	22709	43661		107.01
Grams/fish/day	0.282	0.531	1.000	1.305	1.577	2.205		
Actual amount fed (g)	4132	13083	19218	12798	26450	47000		89.47
Grams/fish/day	0.240	0.515	1.522	1.774	1.837	2.374		
Cage #6								
Theoretical amount fed (g)	4558	12522	11587	8864	23529	43758		105.07
Grams/fish/day	0.287	0.535	0.996	1.333	1.770	2.394		
Actual amount fed (g)	3982	13305	15219	13312	28800	50130		125.00
Grams/fish/day	0.251	0.568	1.308	2.002	2.166	2.742		
Cage #7								
Theoretical amount fed (g)	4164	11575	10658	8576	23812	37068		96.10
Grams/fish/day	0.283	0.534	0.984	1.394	1.935	2.191		
Actual amount fed (g)	4100	13318	14928	13272	32230	42268		120.37
Grams/fish/day	0.279	0.615	1.378	2.157	2.619	2.498		

*Assume a feed:weight gain ratio of 1.25:1

quire further explanation. The high (1.82) conversion factor for cage #3 for the period of May 18 to June 6 is attributed to the fact that feeding was based on 750 fish, prior to the detection of the escape of a large proportion of these (see theoretical and actual amounts of feed/fish/day calculated on basis of 240 fish). Other high values such as those found for cages #2 and #3 are generally associated with the fact that feed was being wasted through overfeeding.

All four cages in the west pond experienced poor feed conversion in the period from August 11 to September 2 just prior to the collapse of pond ecosystem through oxygen depletion. These are probably associated with reduced feeding as a result of stress factors preceding the collapse.

The considerable reduction in the amount of feed provided to cages #2 and #3 in the September 14 to October 21 period should have been expressed in low conversion factors combined with reduced growth rates. Although reduced growth rates were experienced, the high conversion values for both cages (1.98 and 3.45 for cages #2 and #3, respectively) suggest that even the reduced amount of feed provided was too much and that other factors such as temperature were responsible for reduced feeding and reduced growth rate. A partial explanation for the very high value in cage #3 is the escape of approximately 100 of the 240 fish near the end of the season.

4.2.4 Fish Harvest

As a result of the summer fish kill in cages #4 to #7 only those fish in cages #2 and #3 in the east pond and those which had escaped from cage #3 into the pond were available for harvest. A total of 609 fish

were recovered from cage #2. Of these 78 (12.8%) were considered too small to process (generally estimated to weigh less than 200 g) and were placed in an overwintering cage. Total weight of 531 remaining fish prior to processing was 117.08 kg ($\bar{x}$ = 220.5 g). Total dressed weight (heads on) was 92.05 kg or an average of 173.0 g (0.38 lb.). Dressed weight was 78.4% of whole weight.

Cage #3 contained only 130 fish at harvest. One hundred and twenty-six of these were processed. Four were culled into the overwintering cage. The remainder weighed 38.16 kg ($\bar{x}$ = 302.9 g) prior to dressing and 30.0 kg ($\bar{x}$ = 234.4 g) after dressing with a visceral weight loss of 22.6%.

Following the harvest of caged fish, the dugout was seined to recover the fish which escaped from cage #3. The latter included two groups, those which escaped shortly after stocking in May and the 110 which escaped prior to harvest in September or October. Four hundred and forty-eight fish were recovered. Of these 230 were too small to process and were returned to the overwintering cage. The 218 fish processed obtained a whole weight of 43.0 kg for an average weight of 197.4 g. They provided a dressed weight of 35.6 kg ($\bar{x}$ = 158.5 g). Discarded viscera averaged 19.6%.

The difference in visceral weight is due to the amount of undigested food material remaining in the stomach and intestines.

Samples of both the harvested fish and the fish which died in the summer fish kill were examined for differences in flesh colour between those fed with feed coloured with canthaxanthin and those fed noncoloured feed. Some differences in flesh colour were noted ranging from white to pale orange. The differences were not large or consistent among fish

from various cages. The colour intensity achieved was far short of that obtained in stocks fed on natural populations of insects and crustaceans and was considered inadequate to satisfy a discriminating consumer.

The Gammarus culture pond maintained adjacent to the two fish ponds failed to provide sufficient numbers of Gammarus for the experimental program. This aspect of the experiment was deferred until a satisfactory Gammarus supply could be provided.

Comments from consumers about the excessive amounts of mucus on the fish reared in the first year of experimentation were taken into consideration in processing of the 1983 harvest. It was found that washing the dressed fish in a brine solution of sodium chloride caused the mucus to curdle and slough off. The brine performed a dual function of lysing the residual red blood cells in the body cavity thereby facilitating cleaning.

Consumer reaction to questions regarding the taste and acceptability of the cage reared fish were generally favourable. No disagreeable or "muddy" taste was reported. Providing some colour to the flesh would be desirable.

4.2.5 Summer Fish Mortality

A record was maintained of dead fish removed from the cages during the summer. Some of the fish removed were in an advanced stage of decomposition before they surfaced so that an accurate estimate of the date of their death could not be established.

A total fish kill was experienced within one day of stocking of the west pond on May 5. This was attributed to the presence of residual

chlorine in the water from city water supplies used in topping up the pond. Following restocking but prior to the total fish kill experienced in the west pond beginning September 2, only four fish were lost out of a total of 3366 (Table 13). The mortalities occurred on the last day of July and in August and can not be attributed to any specific cause.

In the east pond, 26 fish were lost immediately after stocking. The losses are believed to be associated with the stress of transporting and handling. Following this initial loss only six more fish were lost in the two densely stocked cages. Heaviest fish mortality occurred in the brood stock cage. Of the 77 fish placed in the cage in the spring, 26 dead fish were recovered during the summer. Forty-six fish survived leaving five unaccounted for. The highest loss of brood stock (10) occurred on August 12 and 14, a period when losses were also reported in both cages #2 and #3. These losses are tied to stress conditions resulting from high water temperatures and low dissolved oxygen conditions during that period.

4.2.6 Summer Pond Management - 1983

4.2.6.1 Water Level Management

The west pond (previously not used for aquaculture) was prepared for fish by patching and painting the butyl rubber lining with white rubber based paint. The pond was then topped up with chlorinated water from the city water supply beginning on April 28 and ending May 2, two days before the arrival of the fish. Water samples were taken for chlorine analyses two hours after pumping was stopped. The results of the analyses were as follows:

Table 13. Summer Fish Mortalities, 1983.

East Pond

Cage #1 (Brood Stock)

Date	Mortalities
29.5	1
13.6	4
15.6	1
6.7	1
7.7	1
11.7	1
14.7	3
2.8	1
4.8	1
5.8	2
12.8	7
14.8	3
Total	26

Cage #2

Date	Mortalities
5.5	23
14.7	2
12.8	1
14.8	1
Total	27

Cage #3

Date	Mortalities
5.5	3
12.8	2
Total	5

West Pond

Cage #4

Date	Mortalities
2.9	885

Cage #6

Date	Mortalities
2.9	831

Cage #5

Date	Mortalities
31.7	2
6.8	1
2.9	900
Total	903

Cage #7

Date	Mortalities
14.8	1
2.9	768
Total	769

Sample	Residual Chlorine (mg/L)	Free Chlorine (mg/L)
Tap water	0.15	0.15
Pond water	0.05	0.05
Distilled water	<0.01	<0.01

Following the loss of the first stocking of fish in the west pond due to residual chlorine, the pond was treated with a sodium thiosulphate solution containing 2.7 kg of dry ingredient. The dechlorination was followed by further chemical tests and fish bioassays prior to restocking.

The west pond was topped up with 194,456 litres of water on July 5 to 7 and 64,507 litres on August 22. The east pond received 82,100 litres of water on July 14 and 64,507 litres on August 25. The top up water was dechlorinated with sodium thiosulphate solution (750 g/L) introduced at a rate of 0.026 mL per litre of water containing 1.5 mg/L of chlorine.

4.2.6.2 Algae Control

The fish ponds were visually checked for algal growth. Measurements of Secchi disc transparency were begun on May 24 and were continued intermittently to September 28. The transparency measurements provide an indication of quantities of planktonic algae species. A dense growth of algae developed on the east pond early in May and persisted throughout the season (see Table 14). The Secchi disc was visible through the entire depth of the west pond in the spring. Algal growth clouded the water through the months of June and July. In August, both ponds were comparably fouled by suspended material. At the time of the summer fish kill the 20 cm diameter Secchi disc became invisible at a depth of only 10 cm.

The early spring growth of algae in the east pond was treated with

Table 14. Secchi Disc Transparency (m), 1983.

Date	East Pond	West Pond
May 24	0.5	2.9*
May 26	0.6	2.9
June 1	0.6	1.9
June 6	0.6	2.8
June 8	0.6	2.3
June 13	0.6	2.5
June 15	0.6	1.8
July 4	0.5	--
July 11	0.6	0.9
July 13	0.6	--
July 16	0.5	0.7
July 25	0.7	1.4
July 28	0.7	1.2
August 5	0.3	0.5
August 10	0.6	0.6
August 14	0.8	0.6
August 17	0.7	--
August 25	0.3	0.3
August 30	0.8	0.2
August 31	0.7	0.1
September 5	0.1	0.7
September 9	0.7	0.7
September 12	0.8	--
September 28	0.4	--

*bottom

170 g of copper sulphate. Treatment was undertaken in both ponds on August 12 and 16th. The west pond was treated again on August 31 just before the summer fish kill. The treatments failed to provide any lasting control as evidenced by the continued low Secchi disc readings. However the final treatment of the west pond just prior to its collapse may have been a contributing factor to the fish kill experienced.

Although the two ponds are located adjacent to one another the algal populations were markedly different. The west pond was dominated by yellow-green and diatom species with no filamentous algae whereas the east pond contained a large population of the blue-green alga Microcystis aeruginosa. In addition, the east pond developed a dense mat of the filamentous green algae Cladophora. The Cladophora grew along the shaded west shore of the pond and extended around to the north and south ends. The formation of gas bubbles under the mats of algae caused them to float to the surfaces. Large quantities of the floating mats were raked out, particularly during the months of August and September.

4.2.6.3 Pond Temperatures

Measurements of pond temperature profiles were made in each pond at irregular intervals ranging from one to five days. Data obtained for the period of the experiment are presented in Appendix 3. Surface temperatures reached 20°C in the last week of June and were consistently higher than 20° for the period from July 4 to the end of August. Maximum surface temperatures of 24°C and 25°C were reported for the east and west ponds, respectively, at 2:00 pm on August 10. A fairly rapid decline in temperatures occurred beginning September 3. Within two weeks tempera-

tures were below 10°C. The decline continued to freezeup near the end of October.

Generally, the difference between surface and bottom temperatures was 2 to 3°C on sunny days. A uniform temperature was experienced from surface to bottom on cloudy days.

Management of pond temperatures was considered in the operation of the spray aeration system. Except for periods of critically low dissolved oxygen levels, aerators were operated only from dusk till about 8:00 am when ambient temperatures were lower than water temperatures. The spraying water cooled to provide a general cooling effect for the entire pond. In September when pond temperatures dropped, the aerators were operated during the day to enhance daytime warming and to reduce the nighttime cooling effect.

4.2.6.4 Dissolved Oxygen Levels

Dissolved oxygen measurements were made in the two ponds at the same time that water temperatures were measured. Generally the measurements were made in the morning. Profiles were established at 1 m intervals from surface to bottom (see Appendix 4). Dissolved oxygen levels at the surface in both ponds were at or near saturation until August 8. Critically low oxygen levels were encountered in both ponds in a three week period to the end of August. The east pond experienced surface oxygen levels of 5.2 mg/L on August 12 and 4.8 mg/L on August 30. Subsurface levels ranged downward from 4.5 mg/L at 1 m. Lowest oxygen levels in the west pond were experienced from August 30 to September 1, the period during which the fish kill occurred. As evidenced by the low oxygen

levels in the east pond during this period, that pond also came dangerously close to experiencing a fish kill. The low levels in the east pond on August 11 and 12 coincide with the loss of significant numbers of brood stock. Dissolved oxygen levels recovered rapidly as temperatures dropped in September.

An oxygen gradient was generally reported through the vertical profile of the pond. Lowest levels were reported at the mud interface. Three measurements were taken in the west pond on September 1, 1983, when stressed fish were reported at the surface. The values ranged from 4.2 mg/L at 9:00 am, 9.7 mg/L at 1:30 pm and 10.8 mg/L at 4:45 pm showing the rapid recovery from overnight depletion as a result of photosynthetic activity, and the importance of doing morning measurements in order to obtain daily minimum values.

Two pond aerators were installed in the east pond and one in the west pond and operated as described earlier in order to counter the nighttime oxygen demand of the pond flora and fauna and to replenish dissolved oxygen levels in the water. Nighttime aeration was insufficient to maintain oxygen levels during critical periods in August. Continuous aeration was then employed intermittently at lower ambient temperatures.

4.2.6.5 pH, Alkalinity and Specific Conductivity Measurements

Measurements of pH, alkalinity and specific conductivity were made at approximately one week intervals from the beginning of May to the end of October (Table 15) in the east pond. Measurements in the west pond were discontinued on September 9 one week after the summer fish kill. pH values in the east pond ranged from 10.0 on May 24 to less than 8 in

Table 15. pH, Alkalinity and Specific Conductivity Measurements, 1983.

	East Pond			West Pond		
Date	pH	Alkalinity mg/L $CaCO_3$	Specific Conductivity µmhos/L	pH	Alkalinity mg/L $CaCO_3$	Specific Conductivity µmhos/L
May 4	9.29	114	1100	8.53	97	650
May 10	9.60	--	1100	8.30	--	650
May 24	10.00	91	1100	8.69	98	720
May 30	9.97	73	1180	8.97	94	718
June 6	9.97	71	1200	8.97	84	730
June 13	9.70	71	1210	9.06	90	750
June 21	9.69	82	--	8.97	85	--
July 4	9.01	80	--	9.10	89	--
July 11	8.70	87	1275	9.25	78	1150
July 18	8.60	98	1340	9.34	80	780
July 20	8.45	97	1300	9.17	81	--
July 26	8.56	109	1320	8.30	88	800
August 3	9.20	90	1390	8.90	87	810
August 8	8.95	87	1300	8.92	84	800
August 15	8.45	98	1380	9.30	94	780
August 25	8.28	106	1380	8.83	103	780
August 30	8.46	115	1300	8.86	106	--
August 31	8.30	115	1280	8.71	105	710
September 9	7.38	110	1110	7.46	118	610
September 12	7.28	116	1180			
September 19	7.80	112	930			
October 5	7.65	121	950			
October 12	8.05	114	910			
October 17	7.70	115	950			

September and October. The autumn decline in pH shown in the east pond was only beginning in the west pond when measurements were discontinued. Generally, pH values in the west pond ranged from 8.3 to 9.3 during the summer period.

Alkalinity measurements were in a similar range in the two ponds (Table 15). Values in the east pond ranged from 71 mg/L as $CaCO_3$ in June to 121 mg/L in October. The west pond ranged from 80 to 118 mg/L in the May 4 to September 9 period of measurement. Carbonate alkalinity was reported for the period from May 4 to July 4 in the east pond and again briefly in August. The west pond showed low amounts from May 30 to August 15. Elevated alkalinity levels in the fall are associated with declining temperatures and pH's.

Specific conductivity levels in the east pond were markedly higher than in the west pond reflecting the larger contribution of surface runoff and the lower amount of top up water added. Conductivity levels in both ponds increased during the summer as a result of evaporative concentration and then showed a decline in September.

4.2.6.6 Chemical Analyses

Four series of water samples were taken from near the surface and bottom of each pond for measurement of ammonia levels. In addition a water sample was taken from the west pond on September 6 for nutrient analyses following the collapse of the biological system.

The four ammonia measurements showed progressive increases in both ponds (Table 16). Only slightly higher levels were recorded in samples taken from near the bottom. Water samples taken from the west pond fol-

Table 16. Ammonia Levels (reported as mg/L NH_3 - N) in Surface and Bottom Water Samples, 1983.

	East Pond		West Pond	
Date	Surface	Bottom	Surface	Bottom
June 6	0.03	0.03	0.03	0.03
June 21	0.18	0.18	0.10	0.10
July 11	0.15	0.18	0.23	0.25
August 8	0.22	0.26	0.65	0.74

lowing the fish kill had ammonia levels of 0.13 mg/L. Other parameters measured are shown below:

Total Carbon	46 mg/L
NO_2 - NO_3 Nitrogen	0.13 mg/L
Total Kjeldahl Nitrogen	0.46 mg/L
Total Phosphate as P	1.0 mg/L
Ortho Phosphate as P	1.0 mg/L
Copper	0.05 mg/L

5 DISCUSSION

In 1968 to 1970 experimental stocking of rainbow trout was undertaken in some highly productive shallow lakes and ponds in Manitoba to determine the potential for establishing a trout farming industry in water bodies which normally winterkill (Sunde et al., 1970). Thus the concept of the "put and take" fishery was developed whereby fingerlings ranging from 6 to 8 cm would be stocked in the spring and harvested in the fall at an average weight of 383 g. Although initial trials with advanced fry were not successful, with low recovery rates (17.2%) of fish few of which were of marketable size (280 g), subsequent experiments pointed to an excellent potential for establishing a profitable and extensive trout farming industry. The enthusiastic support for this type of fishery is expressed in the large number of pothole fisheries operating across the prairie provinces.

The low number of commercial operations based on the pothole fishery clearly reflect its limitations with respect to guaranteed production, harvest and fish quality. In 1972, the concept of intensive cage culture of rainbow trout in inland lakes in Manitoba was investigated as a means of improving supply and quality (Whitaker and Martin, 1974). The idea was not new, having been used extensively in the mariculture of fish such as salmon and tuna, and the warm water culture of carp, catfish and tilapia in Europe, Asia, Africa and North America. Although fraught with disease problems the Manitoba study concluded that rainbow trout cage culture was biologically feasible. The economic feasibility of cage culture was, however, less certain because of high cost of fish feed and fingerlings relative to low production.

Intensive culture of fish, including rainbow trout, is being undertaken in Europe (Rosenthal, 1981) using semi-closed recirculating techniques generally in tanks and troughs. However, these are being undertaken at high risk generally because of "...lack of communication between research institutions involved in recycling studies and the industry applying new technologies" (Rosenthal, 1981). Information is lacking on intensive cage culture in closed cold water system characteristic of potholes and farm dugouts in the prairies.

Whitaker and Martin (1974) identified disease as one of the most serious problems facing a cage rearing operation. Two factors in our research have helped overcome this problem: the use of fingerlings from certified disease free stocks, and the use of water bodies which do not contain a natural fish population that might serve to transmit disease. This is not to say that disease, once introduced, would not lead to catastrophic results. Avoidance of disease allowed successful rearing of trout at final densities ranging from 13.7 kg/m^3/cage to 19.9 kg/m^3/cage as compared with recommended loadings of 8.0 kg/m^3 in Whitaker and Martin's (1974) studies. Although satisfactory growth was achieved at stocking rates as high as 106 $fish/m^3$ of cage volume, indications are that stocking rates of about 30 $fish/m^3$ would provide the best growth conditions.

Whitaker and Martin (1974) found that fish weighing 1.7 g at stocking were too small to grow to marketable size in one season considering minimum market size to be 173 g round weight or 142 g dressed weight. Fish weighing 7.8 g if grown for 137 days or longer would produce market size fish. Fingerlings weighing 13.9 g grew to 200 g in 130 days.

They suggested that utilizing the full 176 day ice free period in northern Manitoba would significantly increase final size.

Results of our studies were comparable in many respects. In the first year, fish weighing 41.7 and 50.6 g grew to 205 and 255.6 g, respectively, in 145 days. In the second year fingerlings stocked at 10.3 g grew to 183.8 and 290 g (depending on stocking density) in 170 days, others grew from 9.5 g to 80 and 107.5 g in 108 days. Not only do we agree with Whitaker and Martin that the full ice free period should be utilized to achieve maximum growth but that larger fish should be stocked to take full advantage of the geometric growth rate achieved in the mid July to mid September period.

In marine cage culture and in cage culture in large lakes the stocking density per water body is generally not a limiting factor. Water quality is maintained by the constant flushing action of waves and water currents. In tanks, raceways and cage culture in recirculating systems, the stocking density is governed by the rate of water changes and the efficiency at which recirculated water is rehabilitated. In closed system cold water cage culture where water volume is relatively small, the pond stocking density is limited by the efficiency of the pond in assimilating the nutrients introduced in the fish food. No guidelines were found to suggest a stocking rate for closed systems. Normally a typical farm dugout would sustain about 100 fish on a natural invertebrate diet. Assuming a pond volume of 1500 m^3 a decision was made to stock our pond with 1500 fish or $1/m^3$. Successful cage culture of this number for two successive years suggests that this stocking rate is a relatively safe guideline for new operations. The stocking of a second pond with $2.27/m^3$

or 3400 fish and the resultant loss of all fish near the end of the season does not necessarily suggest that this density is too high, but rather points to the increased risk of higher stocking densities and the need for careful monitoring of pond conditions. Installation of biofiltration systems to augment the pond nutrient assimilation capacity may be necessary.

Muir (1982) identified the most critical environmental requirements for fish culture as those associated directly with respiration, metabolism and ionic regulation, and the transfer of gases and ions across gill surfaces. His article summarizes numerous reviews compiled for salmonid culture and general use (Table 17).

Although rainbow trout are tolerant of a broad range of temperatures and pH levels their effect is generally expressed in the modification of the critical elements shown in Table 17. For example, temperature affects the dissolved oxygen content in water as well as the O_2 affinity of haemoglobin. pH affects the state of dissociation of ammonia in the water as well as the CO_2 - HCO_3 balance.

Of the list of critical parameters identified only three were measured regularly in our studies. These included temperature, dissolved oxygen and pH. Upper lethal temperatures reported for rainbow trout vary from 25.6^{o}C to 29.5^{o}C depending on the acclimation temperature (Hokanson et al., 1977). Hokanson et al. (1977) and Wurtsbaugh and Davis (1977) reported 17.2 and 16.5^{o}C, respectively, as optimum temperatures for growth. Hokanson et al. (1977) found that fish held at 23^{o}C over 40 days experienced no growth. Our studies showed maximum growth during the period from mid July to the end of August which also encompassed the warmest period of the year. Temperatures consistently measured above 20^{o}C with mid afternoon surface temperatures going as high

Table 17. Summary of Critical Elements, Their Limitations and Requirements for Rainbow Trout Culture[1].

Element	Concentration (mg/L)	Effect	Reference
Oxygen	5	minimum sustained level	Forster et al. (1977)
Ammonia	>0.01	growth, health impaired	Burrows (1964); Smith and Piper (1975)
	<0.07	no growth effect, 126 days	Forster and Smart (1979)
	0.103	growth decrease first 2 weeks, thereafter adaptation	Forster and Smart (1979)
NO_2	0.015-0.06	minimum level for methaemoglobinaemia	Wedemeyer and Yasutake (1978)
	0.15	methaemoglobinaemia, 48 hr.	Smith and Williams (1974)
	0.19-0.39	96 hr. LC_{50} dep. fish size	Russo et al. (1974)
	0.55	methaemoglobinaemia, 24 hr, 50% mortality, fingerlings	Smith and Williams (1974) Smith and Williams (1974)
	1.6	50% mortality, yearlings, 24 hrs.	
NO_3	>400	tolerated	Westin (1974)
	>800	stops growth	Berka et al. (1980)
	1300	lethal level	Westin (1974)
CO_2	12-55	increasing nephrocalcinosis	Smart et al. (1978)
	70	no adverse respiratory effect	Albrecht (1977)

[1]Summarized from Muir and Roberts (1982).

as 25°C. Considering the fact that temperatures experienced in the summer of 1983 were unseasonally high, it is our conclusion that, in all probability, water temperature as a single factor will not be limiting to the production of rainbow trout in ponds in western Canada.

Of the three parameters investigated, dissolved oxygen is the most critical in the intensive cage culture in closed ponds. Unlike larger lakes and marine environments where an almost limitless supply of dissolved oxygen is held in reserve and replenished through surface aeration and water currents, the limited dissolved oxygen resource in ponds must be carefully managed. Small pond aquaculture is further contrasted with intensive culture in tanks and raceways where dissolved oxygen is continuously replenished through water recirculation and aeration. The results of our studies confirm the observations of Forster et al. (1977) that rainbow trout can not be sustained at dissolved oxygen concentrations below 5 mg/L. Dissolved oxygen levels in the pond which experienced a fish kill in 1983 dropped from 5.6 to 4.2 at the surface and 5.3 to 3.2 at 1 m during the three days immediately preceding the fish kill.

Minimum dissolved oxygen levels are obtained in the morning hours following an overnight period of oxygen depletion and prior to recovery resulting from photosynthetic activity. Since the efficiency of uptake of dissolved oxygen across the gill membrane is reduced at higher temperatures and methaemoglobinaemic conditions caused by high NO_2 levels, it would be prudent to consider dissolved oxygen levels between 5.5 and 6.0 mg/L as dangerously low for intensive trout culture at temperatures of 20°C or higher. Dissolved oxygen was never in short supply during

periods when surface temperatures were below 18°C.

Papst et al. (1980) found that summer dissolved oxygen depletion resulting in summer fish kills in shallow prairie lakes is dependent on the collapse of algal blooms but is not necessarily a result of a bloom collapse. Other factors such as wind stress and night time temperatures generating thermal instability were also causative factors. In contrast thermal instability may occur in a pond on numerous occasions during the summer (Lakshman, 1971; Sunde and Barica, 1975) but is not necessarily accompanied by oxygen depletion. Papst et al. (1980) suggested that "...a decline in algal biomass as well as a concomitant or subsequent period of thermal instability (mixing) are necessary conditions leading to lake oxygen depletion" and that "...oxygen depletion should not occur when (1) there has been no bloom collapse and there is thermal stability; (2) there has been no bloom collapse and there is thermal instability; (3) there has been a bloom collapse and there is thermal stability."

Our experience has shown that diurnal dissolved oxygen levels fluctuate widely during algal bloom periods ranging from supersaturated conditions during mid afternoon to minimum levels during the early morning period. It is our impression that algal bloom collapses may be self initiated by severe nighttime oxygen depletion. This situation is aggravated by calm cloudy conditions and/or attempts at artificially controlling algae. With sufficient nighttime aeration it should be possible to prevent bloom collapses and oxygen depletion to lethal levels. Daytime photosynthesis builds up oxygen reserves during the mid-day period.

Rainbow trout can tolerate a range of pH from 3.3 to 10.7 depending on factors such as temperature, dissolved oxygen, prior acclimatization and the content of various anions and cations (McKee and Wolf, 1963). The effect of pH on rainbow trout in culture is most frequently expressed in its control of the ionization state of ammonia. Low concentrations of unionized ammonia decrease growth rate, physical stamina and disease resistance and promote clubbing of gill filaments in fish (Sousa et al., 1974). Lowering the pH has the effect of shifting the NH_3/NH_4^+ ion. Culturing fish under mildly acidic conditions would permit the accumulation of higher levels of ammonia without harm. The high pH levels experienced in our study suggest that artificial manipulation of pH should be possible to reduce the toxicity of ammonia should this become a problem.

Traditionally, fish held in cages or raceways were fed artificial feeds manually one or more times a day. Since this aspect of aquaculture is the most labour intensive and time demanding, methods have been developed to feed fish automatically either by demand feeders or mechanical feeders which dispense prescribed amounts of feed at prescribed intervals. This has been made possible by the development of standard uniform sized granular, flaked and pelletized feeds. One of the first demand feeders was developed by B. Thüring (BRD 8671 Hohenmühle/ Oberfranken) in the Federal Republic of Germany during the late 1960's (Liebman, 1970) when it was learned that fish can be trained to press a lever to obtain food. Adron (1972) described an automatic feeder suitable for either timed operation, or with a trigger for demand feeding. Adron et al. (1973) were able to show an 8 hour cycle of feeding in con-

tinuous light. Grove et al. (1978) found that feeding cycles recurred about every 5 to 6 hours, appetite being triggered by the fact that the stomach would be 80-90% empty after 6 hours. Landless (1976) found that trout could be trained to feed within 24 hours. Trout left to train on their own appeared to feed at a generally lower level for the first 6 days after which feeding rate became similar to the trained trout. He found that trout preferred to feed at intervals of 4 to 8 minutes. A diurnal pattern of feeding activity was demonstrated with a clear feeding peak at dusk with a less clear peak at dawn. An appreciable amount of overnight feeding was also evident. This was not associated with a high wastage to indicate that the fish were eating the food dispensed. Landless (1976) confirmed an 8 hour feeding cycle similar to that found by Adron et al. (1973).

In rainbow trout fed on dry pellets about 40% of the stomach contents is emptied over an 8 hour period at 12^{o}C in 30 g trout (Windell et al., 1972). Landless (1976) noted that it is generally accepted that feeding to satiation leads to low conversion efficiency. Excessive feeding adds little to the growth, but may be harmful to the fish (Sumari and Westman, 1972). Frequent feeding may also affect digestibility by forcing food through the digestive tract too fast to achieve maximum absorption. According to Thüring (1968) there is no danger of over feeding when fish are fed with a demand feeder because the fish eat only when hungry. However, Bohl (1969, from Sumari and Westman, 1972) found that at the beginning of his experiments trout ate as much as 6.8% of their body weight daily resulting in mortality from over feeding. When feeding was resumed after 8 days the fish ate from 2.4 to 3.0% of their

body weight per day. The danger of over feeding is expecially high if the fish are used to getting food only once or twice per day.

Sumari and Westman (1972) compared hand feeding with demand feeding. They found that fish fed with a self feeder (B. Thüring type) grew as well as fish fed by hand three times a day. There were also no significant differences in mortality, condition or weight frequency distribution. Bohl (1969) similarly found that growth of rainbow trout fed with Thüring's self feeder was as good as that of trout fed by hand twice a day ad libitum. This conversion of food with two types of pellets was 1.6 and 2.9 using the self-feeder and 1.6 and 3.2 when hand fed. Liebman (1970) noted that growth in fish fed with the self-feeder can be double that of fish fed by hand.

Demand feeders were used during part of the first season of our program. Continuing problems with the rate at which feed was dispensed and frequency bridging caused by a combination of poor feeder design and poor feed led to their being abandoned in favor of automating feeders dispensing feed at regular intervals. The switch to automatic feeders resulted in a large drop in the feed conversion ratio suggesting that the demand feeder was wasting a considerable amount of feed. Landless (1976) found that some trout held individually and fed by demand feeder tended to waste feed but where a larger number was held together the food was all eaten by other fish.

In the second year of our study automatic feeders were used to dispense a prescribed amount of feed at two hour intervals during the daylight hours (generally 8 times/day). Although no literature was found comparing frequent automatic feedings with demand or hand feeding, the

conclusion of Sumari and Westman (1972) suggest that "...at least when the food is given by hand, nothing is gained by feeding yearling rainbow trout more frequently than 2-3 times a day." This is supported by Grove et al. (1978) who note that ideally, food should become available when appetite has returned since, if the fish are feeding synchronously, uneaten pellets are not only wasted, but will contaminate the water. With stomach evacuation and the return of appetite returning at approximately 6 hour intervals, feeding at 2 hour intervals probably caused the fish to eat less food than they would have if fed less frequently. Grayton and Beamish (1977) compared feeding frequencies from one meal every second day to six meals per day. They found maximum daily food intake with just two feedings to satiation per day. The general lack of response to feeding frequency was attributed primarily to the low metabolic rate of trout and to the slow passage of food in the digestive tract.

The fish reared on the more frequent feedings appeared to show greater size variability than those fed by demand feeder and by hand the previous year. The variability may be due to the stocks used or the establishment of a hierarchy within the cages wherein the larger fish get all of the food. A hierarchy was noted by Landless (1976) in his demand feeder experiments wherein a small number of large fish always tripped the feeder mechanism. In his study, however, there was no evidence that the smaller fish in the group were deprived of food to the point of losing condition. In our study, it is possible that the frequent dispensing of small quantities of food serves to feed only the larger fish while the small ones are deprived. On the basis of the

evidence provided it would appear desirable to feed larger quantities of feed less frequently to ensure that all fish are satisfied and then deprived of food for long enough to develop an appetite.

Demand feeders have desirable features in that fish can have control over their own food requirements. The absence of/or reduction in feeding activity would signal some physical or health problems. Finally, demand feeders, if designed properly and supplied with good quality feed could function relatively maintenance free. Demand feeders tend to overfeed fish newly introduced to this mode of feeding. Grizzell (1969) noted that early demand feeders were not practical in fingerling ponds since fingerlings must be about 20 cm in length before they are heavy enough to make the trigger operate. These problems have generally been overcome.

Our experiments were not designed to evaluate feed quality, feeding rates, feed intake and wastage. It was noted that some feed pellets used tended to fragment and create problems with automatic and demand feeders through bridging and plugging. The user should look to using pellets top dressed with fish oil to reduce crumbling and to minimize handling. Feeding rates recommended by feed producers and by Piper et al. (1982) range from 2-3% of body weight per day. This is consistent with feeding rates reported by Bohl (1969, from Sumari et al., 1972) using demand feeders.

One of the appealing features of pond reared rainbow trout in western Canada is the orange flesh colour derived from the carotenoid pigments in Gammarus and other aquatic crustaceans. The rearing of trout in cages deprives them of this natural dietary supplement resulting in white fleshed fish. Experiments have been undertaken to determine

whether shrimp wastes containing the carotenoid asthaxanthin could be incorporated in trout diets to produce coloured flesh (Choubert and Luquet, 1983). Success has been limited due to the poor digestability of the pigment material. Bauernfeind (1976) found that canthaxanthin ($4,4^1$-diketo-β-carotene) a widespread naturally occurring pigment is capable of enhancing flesh colour in trout. Canthaxanthin fed to rainbow trout at a rate of 19 mg/kg of feed for 31 weeks produced an orange-red flesh colour that was heat stable confirming results of Deufel (1965) and Lambersten and Braekkan (1971) in European experiments (from Bauernfeind, 1976).

Our experiments used commercially available pigmented feeds to enhance the flesh colour of our trout. Maintenance levels of canthaxanthin were incorporated in the fish feed at a rate of 500 mg/kg. The pigmented feeds fed for the duration of the experiments failed to achieve significant differences in flesh colour from the controls. These results contradict the reported successes of fish farmers in Ontario (Robbins[1], Pers. Comm.) who use pigmented feeds from a different supplier.

Mathias et al. (1982) investigating the nutritional quality of Gammarus lacustris for trout culture found that rainbow trout fed with G. lacustris had brighter external colouration than those fed commercial feed. The effect on flesh colour was not apparent at the end of the month-long feeding experiment. The authors suggest that this may be due to the small size of fish used or the deterioration of flesh quality in the 30 month period of storage before analyses were completed. Our

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[1]N. Robbins, Trillium Springs Fish Farms Ltd., Holland Centre, Ontario.

studies intended to pursue the concept of using live Gammarus to enhance flesh colour, however sufficient stocks of the crustaceans could not be established.

Continuous light was used to attract flying insects to the fish cages and to determine whether continuous light modified growth of rainbow trout. Although there was some indication that light and/or insects enhanced fish growth in the first year the results are inconclusive because of differences in stocking densities, and feeding problems. The results could not be confirmed in the second year for similar reasons.

6 CONCLUSIONS

This study has demonstrated that intensive cage culture of rainbow trout can be successfully undertaken in farm ponds without the need for recirculating water. Successful rearing of 1500 fish per dugout ($0.86/m^3$) has been demonstrated for two seasons at a stocking density of 750/cage ($88/m^3$). Higher numbers may be stocked but require careful monitoring of pond conditions, particularly dissolved oxygen levels.

The rearing of trout in cages insures 100% recovery at harvest with minimum time and effort. The enclosures provide opportunities for the monitoring of fish growth and conditions and offer flexibility for harvest with respect to timing market availability and market requirements.

Preliminary evidence shows that a stocking density of 100 fish/m^3 of cage volume should not be exceeded and that optimum growth rates are achieved at densities of about $60/m^3$. Maximum rate of growth is achieved from mid July to mid September. In order to take maximum advantage of this growth period fish should be stocked as early as possible in the spring. The fingerlings should be as large as possible. It should be possible to obtain fish with a dressed weight of 350 g (0.75 lb) in one growing season with fingerlings 12 cm long stocked at a cage density of $30/m^3$.

Feeding rates calculated on the basis of the Piper et al. (1982) formula assuming a feed conversion rate of 1.25 provided optimum feed conversion during the mid summer period but are too high during the period of declining water temperatures from mid September to freezeup. Feed conversion ratios of 1.25 maintained throughout the season appear ideal for achieving optimum growth. Ratios lower than this value suggest

underfeeding. Higher values suggest overfeeding. Feed conversion ratios should be calculated periodically to evaluate fish performance and to make most efficient use of feed in order to reduce costs and avoid excessive nutrient loading in the pond.

The effect of feeding frequency during the daylight hours has not been fully evaluated. Preliminary indications are that feeding more than two or three times per day is not necessary and may infact encourage the establishment of a pecking order causing the smaller fish to get insufficient feed.

In view of the difficulties experienced with feed quality and feeders, studies into the effects of insects as a food supplement and the effects of continuous lights on fish growth are inconclusive. Similarly, feeding of trout with artificially pigmented feeds in order to induce an orange flesh colour yielded inconclusive results.

The intensive rearing of rainbow trout in closed pond systems introduces large quantities of nutrients which become expressed in the prolific growth of planktonic and attached algae. The algae perform a desirable function in reducing levels and converting toxic nutrients such as ammonia and nitrite as well as increasing dissolved oxygen levels through photosynthetic activity. Conversely, dense algal growth places a severe nighttime dissolved oxygen demand on the pond ecosystem through cell respiration and cell decomposition. Careful pond management is required to reduce the risk of algal bloom collapse. Control of algal growth particularly during hot mid summer periods is not recommended.

Nighttime dissolved oxygen depletion is the single most serious

hazard to intensive pond culture systems. Aeration devices are required to sustain dissolved oxygen above lethal limits. Although diffuser aerators work well they have not been demonstrated as the most effective options. Further work is required to demonstrate their efficiency, to determine the numbers of aerators required, and the need for and type of auxiliary backup aeration. Our studies provided nighttime aeration in order to supply oxygen during the most critical period. This period of aeration also provides nighttime cooling of the water and allows maximum uptake of oxygen by the cooler water. It is believed that sufficient pond aeration can prevent algal population crashes and the anoxic conditions which follow. Aeration would provide for gradual population declines which would be governed by parameters such as nutrients and temperature.

7 RECOMMENDATIONS FOR FURTHER STUDY

1. Preliminary data show that stocking density per cage has a marked effect on fish growth and that maximum growth can be achieved by stocking smaller numbers of fish in a larger number of cages in order to achieve the same stocking density. Studies should be undertaken to determine the optimum stocking density per cage.

2. The highest rate of growth is achieved from mid July to mid September. Stocking of larger fingerlings should capitalize on this geometric growth period. Studies should be undertaken to assess the importance of size of fingerlings and the importance of stocking date in achieving maximum production.

3. Preliminary evidence shows that timed feeders provide more efficient use of feed than demand or manual feeding, however too frequent feeding may cause a spread in size range as a result of establishment of individual dominance. Studies should be conducted to show the effect of feeding frequency on size range distribution and feed conversion.

4. The results of the use of maintenance levels of flesh colouring agents in inducing an orange flesh colour were inconclusive. Further studies are required to determine whether the use of artificial pigments in inducing flesh colour is possible or practical.

5. Although 1500 rainbow trout were successfully cultured in a pond in two successive years a severe deterioration in water quality appeared in the second year. Chemical analyses are required to provide a quantitative assessment of change in quality and to assess whether sustained production can be undertaken at this rate.

6. The attempted culture of 3000 fish in one pond, though unsuccess-

ful, provided valuable clues with respect to stocking densities and stress indicators. Further studies should be undertaken to clearly establish the risks of high density pond culture and to develop mechanisms to overcome these risks.

7. Pond aeration systems used in our experiments, though apparently adequate, need to be evaluated with respect to efficiency under a variety of pond conditions, operating costs and other aeration options.

8. Continuous pond monitoring and alarm systems should be evaluated to provide protection against critical parameters such as low dissolved oxygen.

9. The use of aeration systems to control sudden algal population collapses should be investigated further.

10. The filamentous green alga Cladophora appears to play an important role in the maintenance of pond dissolved oxygen levels and nutrient balance. Studies should be undertaken into the desirability of selectivelly growing this species for pond maintenance in competition with less desirable species such as blue green algae and diatoms.

11. The Saskatchewan Research Council aquaculture site provides an ideal experimental situation for demonstrating biological nutrient removal from a pond aquaculture system by cycling water through an aquatic plant pond. The feasibility of such operations should be evaluated for use in situations where water supplies are limiting.

12. Pond polyculture systems have been shown to be very effective in pond management and increasing productivity. It is recognized that waste feed and faecal material provide an ideal substrate for chironomid or midge larvae which in turn are the preferred food for lake whitefish.

Studies should be undertaken to determine the feasibility of rearing rainbow trout in cages and lake whitefish free ranging in the pond.

13. The polyculture of Gammarus with rainbow trout is another option wherein the Gammarus would feed on waste food and faecal material and would in themselves provide supplementary food for the fish. The Gammarus, known to enhance flesh colour in trout could provide a triple function in pond contaminant control, fish food, and colour enhancement.

14. Preliminary studies have shown that rainbow trout triple or quadruple their weight in their second season of growth. Strategies should be developed for growing fish for two or more seasons to maximize returns.

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APPENDICES

Appendix 1. Pond Temperature (^{o}C) Measurements, 1982.

		Depth (m)			
Date	Time	Surface	1.0	2.0	3.0 (Bottom)
June 3	6:30 pm	15.5	--	--	--
June 5	9:00 am	17.8	--	--	--
June 5	9:00 pm	18.8	--	--	--
June 6	10:00 am	16.2	--	--	--
June 6	7:00 pm	16.0	--	--	--
June 7	8:00 am	14.2	--	--	--
June 7	4:00 pm	15.0	--	--	--
June 8	4:30 am	14.6	--	--	--
June 8	9:00 pm	16.0	--	--	--
June 9	8:00 am	15.0	--	--	--
June 9	5:00 pm	16.4	--	--	--
June 10	9:00 am	15.4	--	--	--
June 10	8:00 pm	16.4	--	--	--
June 11	8:30 am	15.0	--	--	--
June 12	8:00 am	16.4	--	--	--
June 12	9:00 pm	16.6	--	--	--
June 13	9:00 am	17.4	--	--	--
June 13	9:00 pm	18.4	--	--	--
June 14	9:00 am	18.4	--	--	--
June 14	7:00 pm	19.0	--	--	--
June 15	5:00 am	18.8	--	--	--
June 15	7:30 pm	19.3	--	--	--
June 16	8:00 am	18.4	--	--	--
June 16	4:00 pm	19.8	--	--	--
June 17	11:00 am	19.1	--	--	--
June 18	9:15 am	19.0	--	--	--
June 18	5:15 pm	19.0	--	--	--
June 21	3:00 pm	20.0	--	--	--
June 23	8:00 am	21.0	--	--	--
June 23	5:00 pm	20.0	--	--	--

Appendix 1. (Continued)

Date	Time	Depth (m)			
		Surface	1.0	2.0	3.0 (Bottom)
June 24	8:00 am	18.5	--	--	--
June 24	1:00 pm	19.0	--	--	--
June 25	10:30 am	17.0	16.8	16.2	15.5
June 25	4:00 pm	20.5	--	--	--
June 25	9:00 pm	20.2	--	--	--
June 28	8:00 pm	19.0	--	--	--
June 30	8:00 pm	19.2	--	--	--
June 30	4:00 pm	19.2	--	--	--
July 7	2:30 pm	18.9	--	--	--
July 8	10:30 am	18.5	--	--	--
July 11	?	21.0	--	--	--
July 12	9:15 am	--	21.5	--	--
July 15	4:30 pm	21.0	--	--	--
July 16	11:00 am	20.0	--	--	--
July 17	9:00 am	19.5	--	--	--
July 18	9:30 am	19.5	--	--	--
July 19	10:00 am	21.0	--	--	--
July 21	9:00 am	19.5	--	--	--
July 22	3:00 pm	20.6	--	--	--
July 23	9:30 am	19.2	--	--	--
July 24	10:30 am	19.4	--	--	--
July 26	2:00 pm	20.2	--	--	--
July 27	12:00 pm	21.0	20.5	20.2	18.2
July 29	?	21.5	--	--	--
July 30	11:00 am	21.5	--	--	--
July 31	12:00 pm	21.8	--	--	--
August 1	12:00 pm	22.0	--	--	--
August 2	11:00 am	21.0	21.2	21.2	18.0
August 4	12:00 pm	21.2	--	--	--
August 5	?	21.0	--	--	--

Appendix 1. (Continued)

Date	Time	Depth (m)			
		Surface	1.0	2.0	3.0 (Bottom)
August 6	?	22.3	--	--	--
August 7	5:00 pm	21.0	21.0	21.0	19.5
August 8	5:00 pm	22.0	--	--	--
August 9	?	20.2	--	--	--
August 11	2:00 pm	20.5	20.0	19.0	19.5
August 12	1:30 pm	19.9	19.9	19.9	19.0
August 15	10:45 am	18.0	--	--	--
August 16	?	21.0	20.5	19.8	19.0
August 18	?	20.2	--	--	--
August 19	?	22.0	20.9	20.5	19.5
August 20	?	21.8	--	--	--
August 24	11:00 am	18.5	18.5	18.5	18.4
August 30	3:30 pm	14.0	14.0	14.0	14.0
September 1	?	14.5	14.5	14.5	14.2
September 2	?	16.5	--	--	--
September 6	4:00 pm	15.0	15.0	14.9	14.9
September 8	3:05 pm	17.0	16.9	15.5	14.2
September 10	1:00 pm	15.8	15.8	15.8	14.8
September 13	2:30 pm	12.5	12.5	12.5	12.5
September 15	4:30 pm	11.4	11.4	11.4	11.4

Appendix 2. Pond Temperature (°C) Measurements, 1983.

		East Pond				West Pond			
Date	Time	Surface	1 m	2 m	3 m	Surface	1 m	2 m	2.5 m
May 4	1:00 pm	9.2	8.0	8.0	7.1	9.0	9.0	9.0	9.0
May 6		10.9	--	--	--	10.2	--	--	--
May 9		11.0	--	--	--	11.0	--	--	--
May 10	3:00 pm	5.9	--	--	--	5.9	--	--	--
May 11	10:00 am	5.0	--	--	--	5.0	--	--	--
May 12		5.5	--	--	--	5.5	--	--	--
May 16		9.8	--	--	--	9.8	--	--	--
May 24	12:00 pm	13.0	11.5	11.0	6.5	12.0	10.8	10.8	10.8
May 25	2:00 pm	14.0	13.8	13.8	13.8	14.0	12.0	12.0	12.0
May 26	1:00 pm	17.0	14.0	13.5	13.5	15.5	14.8	14.8	14.8
May 27	11:00 am	15.0	--	--	--	15.0	--	--	--
May 30	9:00 am	13.5	13.5	13.0	13.0	14.0	14.0	14.0	14.0
June 1		15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0
June 3		13.0	13.0	13.0	13.0	13.0	13.0	13.0	13.0
June 6	10:30 am	15.1	13.8	13.5	13.8	15.1	14.5	14.2	13.8
June 8	2:30 pm	20.0	15.0	15.0	13.8	18.4	17.5	16.0	16.0
June 13		17.0	16.0	15.5	11.0	17.0	17.0	17.0	16.5
June 14	7:00 am	15.5	15.0	15.0	13.5	--	--	--	--
June 15	11:00 am	17.0	16.0	15.8	15.0	17.0	16.5	16.5	15.8
June 16	6:30 am	16.0	16.0	15.0	13.0	--	--	--	--
June 20		17.0	17.0	17.0	15.5	17.0	17.0	17.0	17.0
June 24		22.0	18.0	17.5	16.0	21.5	19.0	18.5	18.0
June 27		18.0	16.5	16.0	16.0	18.0	17.0	17.0	17.0
June 28		17.0	17.0	17.0	16.3	17.5	17.5	17.2	17.1
July 4		20.5	18.5	17.5	17.0	21.0	21.0	19.0	18.0
July 6	10:00 am	21.0	19.5	18.9	17.8	21.0	19.8	19.6	18.0
July 8	8:30 am	21.0	21.0	21.0	17.0	21.0	21.0	21.0	18.0
July 11	1:00 pm	22.8	20.1	19.5	19.0	22.5	20.1	19.4	19.1
July 13	10:30 am	22.0	20.8	20.5	19.0	22.0	21.0	20.8	19.0
July 16	10:00 am	20.0	20.0	20.0	20.0	20.1	20.1	20.0	20.0
July 18		22.9	19.8	19.0	18.9	23.0	20.0	19.0	18.5
July 20	9:00 am	21.0	21.0	20.3	19.0	21.0	21.0	20.0	16.3
July 22	3:00 pm	20.0	20.0	20.0	19.6	20.0	20.0	20.0	19.5
July 25	2:00 pm	23.1	20.8	20.0	19.8	23.9	21.8	21.2	17.4
July 26	10:30 am	21.5	21.4	21.4	20.0	--	--	--	--
July 28	2:00 pm	21.5	20.9	20.0	20.0	22.0	21.2	21.0	20.3
August 3	9:00 am	22.0	21.5	21.0	19.8	23.0	22.5	22.0	20.0
August 5	10:00 am	22.5	22.2	22.0	19.5	23.2	23.2	23.0	21.0
August 8		21.0	21.0	21.0	21.0	22.0	22.0	22.0	22.0
August 10	2:00 pm	24.0	21.2	20.6	20.0	25.0	21.8	21.4	20.0
August 11	11:15 am	21.2	21.0	20.5	20.0	21.2	21.0	21.0	21.0
August 12		20.5	20.5	20.5	20.5	20.5	20.5	20.5	20.5
August 15		22.0	20.0	19.5	19.2	21.0	20.5	19.5	19.0
August 17	2:30 pm	23.0	21.0	20.0	19.0	23.0	21.5	21.5	--
August 23	10:00 am	18.8	18.3	18.0	18.0	18.5	18.2	17.5	--
August 25	9:00 am	19.3	19.2	19.2	19.0	20.3	20.0	19.5	18.5
August 26	8:45 am	20.7	19.8	19.3	19.0	20.2	20.1	18.5	18.0
August 30	9:00 am	19.8	19.8	19.8	19.0	19.9	19.0	19.0	17.0
August 31	8:45 am	20.0	20.0	20.0	20.0	20.5	20.3	19.0	19.0
September 1	9:00 am	--	--	--	--	21.0	21.0	19.0	--
September 1	1:30 pm	--	--	--	--	22.5	22.0	19.0	--
September 1	4:45 pm	--	--	--	--	23.0	22.0	19.8	--

Appendix 2. (Continued)

Date	Time	East Pond				West Pond			
		Surface	1 m	2 m	3 m	Surface	1 m	2 m	2.5 m
September 2	10:30 am	--	--	--	--	22.0	21.5	21.0	--
September 6	2:00 pm	15.5	14.9	14.5	14.5	15.5	14.9	14.5	14.5
September 7	8:45 am	14.0	13.0	13.0	13.0	13.8	13.8	13.8	13.8
September 8	9:40 am	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0
September 9	9:00 am	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0
September 11	1:00 pm	14.5	13.5	12.5	--	--	--	--	--
September 12	10:00 am	12.3	12.2	12.2	12.2	--	--	--	--
September 13	11:00 am	13.0	12.5	12.0	12.0	--	--	--	--
September 14		11.8	11.8	11.8	11.8	--	--	--	--
September 15	8:00 am	11.0	11.0	11.0	11.0	--	--	--	--
September 16	8:00 am	11.0	11.0	11.0	11.0	--	--	--	--
September 18	1:30 pm	8.7	8.7	8.7	8.7	--	--	--	--
September 19	8:00 am	7.0	7.0	7.0	7.0	--	--	--	--
September 20	8:00 am	5.5	5.5	5.5	5.5	--	--	--	--
September 22	10:00 am	6.0	6.0	6.0	6.0	--	--	--	--
September 23	12:00 pm	7.0	7.0	6.8	6.5	--	--	--	--
September 26		10.0	9.5	9.0	9.0	--	--	--	--
September 28		3.8	3.8	3.8	3.8	--	--	--	--
October 5	9:00 am	6.5	6.5	6.5	6.5	--	--	--	--
October 12	9:00 am	5.0	5.0	5.0	5.0	--	--	--	--
October 17	7:30 am	4.0	4.0	4.0	4.0	--	--	--	--

Appendix 3. Pond Dissolved Oxygen Levels (mg/L), 1982.

		Depth (m)			
Date	Time	Surface	1.0	2.0	3.0 (Bottom)
June 25	10:00 am	9.8	9.8	8.0	6.9
July 8	10:30 am	7.2	--	--	--
July 15	4:30 pm	8.2	--	--	--
July 16	11:00 am	7.8	--	--	--
July 17	9:00 am	7.2	--	--	--
July 18	9:30 am	7.9	--	--	--
July 19	10:00 am	8.2	--	--	--
July 21	9:00 am	7.4	--	--	--
July 22	3:00 pm	7.6	--	--	--
July 23	9:30 am	6.8	--	--	--
July 24	10:30 am	6.8	--	--	--
July 26	2:00 pm	6.9	--	4.0	0.8
July 27	12:00 pm	8.0	7.1	7.1	0.6
July 29	5:00 pm	7.2	--	--	--
July 30	11:00 am	7.6	--	--	--
July 31	12:00 pm	7.3	--	--	--
August 1	12:00 pm	7.6	--	--	--
August 2	11:00 am	6.6	6.6	6.6	0.8
August 4	12:00 pm	6.7	--	--	--
August 5	am	6.1	--	--	--
August 6	?	6.9	--	--	--
August 7	5:00 pm	7.1	7.1	6.9	0.9
August 8	5:00 pm	6.2	--	--	--
August 9	?	6.1	--	--	--
August 11	2:00 pm	6.9	6.3	5.9	4.0
August 12	1:30 pm	5.9	5.4	5.2	2.5
August 15	10:45 am	5.3	--	--	--
August 16	?	7.4	7.2	6.4	5.5
August 18	?	6.6	--	--	--
August 19	?	7.2	6.9	6.8	1.5

Appendix 3. (Continued)

Date	Time	Depth (m)			
		Surface	1.0	2.0	3.0 (Bottom)
August 20	?	7.2	--	--	--
August 24	11:00 am	6.8	6.7	6.7	5.2
August 30	3:30 pm	7.0	7.1	7.2	7.4
September 1	?	7.4	7.5	7.4	3.0
September 2	?	7.5	--	--	--
September 6	4:00 pm	6.6	6.4	6.1	5.8
September 8	3:05 pm	8.3	8.1	7.8	4.0
September 10	1:00 pm	7.1	7.1	7.1	2.0
September 13	2:30 pm	6.8	6.8	6.8	6.8
September 15	4:30 pm	8.2	8.2	8.2	6.0

Appendix 4. Dissolved Oxygen Measurements (mg/L), East Pond, 1983.

Date	Depth (m)						
	Surface	0.5	1.0	1.5	2.0	2.5	3.0 (Bottom)
May 4	14.8	--	--	--	--	--	14.0
May 11	12.2	--	--	--	--	--	--
May 24	--	14.0	14.2	--	13.0	--	1.3
May 26	12.0	--	12.0	--	11.0	--	2.2
May 30	--	10.4	10.4	--	10.0	--	2.1
June 1	--	11.8	11.8	--	11.8	--	6.0
June 3	--	--	9.8	--	9.8	--	9.8
June 6	--	11.3	11.8	11.3	10.4	9.9	1.5
June 8	--	11.1	14.2	--	12.2	--	4.0
June 13	--	7.2	6.9	--	6.5	--	1.0
June 14	7.1	--	6.4	--	6.2	6.2	2.5
June 15	--	7.8	7.6	--	6.4	6.0	0.7
June 16	--	7.8	7.8	--	7.6	--	1.0
June 20	--	10.2	10.2	--	7.8	6.5	4.2
June 24	--	--	11.0	--	7.5	5.0	1.0
June 27	8.8	--	8.0	--	6.0	5.2	2.5
June 28	8.3	--	8.0	--	7.4	6.2	2.0
July 4	9.8	--	8.4	--	5.6	4.1	2.9
July 6	9.0	--	8.6	--	7.2	4.0	1.5
July 8	5.2	--	5.3	--	5.2	--	0.5
July 11	8.0	--	6.9	5.6	4.6	3.5	2.3
July 13	8.0	--	7.6	6.4	5.8	5.8	3.5
July 16	5.6	--	5.2	--	4.9	4.7	--
July 18	8.6	--	8.2	--	6.0	4.9	4.0
July 20	7.8	--	7.6	--	7.3	6.3	1.4
July 22	8.3	8.1	8.0	7.4	7.2	6.6	5.5
July 25	10.5	9.4	8.8	8.1	6.9	6.4	5.2
July 26	8.0	7.9	7.9	7.8	7.5	5.7	1.8
July 28	11.9	11.9	11.6	8.4	7.9	7.6	6.4
August 3	9.6	9.0	7.9	7.4	6.6	4.0	1.0
August 5	8.6	7.8	7.6	6.8	6.4	4.2	0.5

Appendix 4. (Continued)

Date	Depth (m)						
	Surface	0.5	1.0	1.5	2.0	2.5	3.0 (Bottom)
August 8	6.4	6.4	5.2	4.2	2.0	1.8	1.8
August 10	7.0	--	4.2	--	2.8	1.4	0.2
August 11	5.8	--	4.8	--	3.9	3.6	2.2
August 12	5.2	--	4.5	--	4.2	0.5	0.5
August 15	7.9	--	6.2	5.1	4.4	3.8	3.0
August 17	10.0	6.8	6.2	5.4	4.2	2.2	0.3
August 20	5.6	--	--	--	--	--	--
August 22	6.4	--	5.8	5.6	5.6	5.5	4.4
August 25	11.5	11.0	12.0	10.9	10.1	8.0	3.0
August 26	5.3	4.6	4.4	4.2	3.9	2.9	2.9
August 30	4.8	4.6	4.6	4.4	4.2	3.2	2.4
August 31	5.0	5.2	5.1	5.1	4.0	4.0	1.5
September 5	9.5	8.4	8.2	7.8	7.4	7.1	6.6
September 7	6.8	6.8	6.6	6.4	5.9	5.4	--
September 8	9.8	9.8	9.6	9.6	9.6	9.6	5.6
September 9	10.0	10.0	10.0	10.0	10.0	--	8.0
September 11	8.9	--	8.1	--	8.0	7.5	7.2
September 12	7.6	7.3	7.1	7.0	6.9	7.0	--
September 13	8.8	--	8.1	--	7.5	7.4	7.3
September 14	8.1	8.0	7.9	7.9	7.9	7.9	--
September 15	8.1	--	7.9	7.9	7.9	7.9	7.8
September 16	8.6	--	8.6	8.6	8.6	8.6	8.4
September 18	11.0	--	11.0	11.0	11.0	11.0	11.0
September 19	9.9	--	9.7	9.7	9.7	9.7	9.7
September 20	11.0	--	10.5	10.5	10.5	10.5	10.5
September 22	10.8	--	10.6	--	10.2	10.2	10.2
September 26	11.0	11.0	10.3	10.0	10.0	9.0	--
September 28	12.8	12.8	12.8	12.8	12.8	11.9	--
October 5	10.9	--	10.9	--	10.8	--	10.8
October 12	12.0	--	11.5	--	11.0	--	11.0

Appendix 5. Dissolved Oxygen Measurements (mg/L), West Pond, 1983.

	Depth (m)					
Date	Surface	0.5	1.0	1.5	2.0	2.5 (Bottom)
May 4	10.5	--	10.5	--	10.5	10.5
May 11	12.0	--	--	--	--	--
May 24	11.0	11.0	11.0	--	11.0	6.5
May 26	10.2	--	10.2	--	10.2	10.2
May 30	--	9.8	9.8	--	9.8	3.1
June 1	--	10.2	10.2	--	10.2	10.2
June 3	--	--	9.8	--	9.8	9.8
June 6	--	9.5	9.6	9.4	9.5	8.0
June 8	--	9.8	10.2	--	11.0	11.0
June 13	9.0	--	9.0	--	9.0	9.0
June 15	--	9.0	9.0	--	9.0	9.0
June 20	--	7.9	7.9	--	7.9	7.9
June 24	--	--	9.9	--	9.8	9.7
June 27	9.4	--	9.5	--	9.5	9.0
June 28	9.8	--	9.8	--	9.6	9.3
July 4	10.2	--	10.7	--	10.7	9.3
July 6	10.0	--	10.0	--	9.6	8.1
July 8	8.4	--	8.4	--	8.0	4.6
July 11	8.7	--	8.9	--	7.7	6.9
July 13	9.9	--	9.8	--	8.0	3.0
July 16	7.8	--	7.6	--	7.2	6.9
July 18	9.0	--	7.4	7.2	6.5	5.2
July 20	7.6	--	7.2	--	6.0	1.0
July 22	7.4	--	7.2	--	6.5	5.5
July 25	7.2	--	6.1	--	6.0	0.6
July 28	7.9	7.8	7.5	7.3	7.0	2.8
August 3	8.9	--	8.0	--	6.6	0.8
August 5	8.1	--	7.1	--	6.6	0.6
August 8	8.1	--	7.5	6.5	6.5	2.2
August 10	10.4	--	7.0	--	5.8	0.8

Appendix 5. (Continued)

Date	Depth (m)					
	Surface	0.5	1.0	1.5	2.0	2.5 (Bottom)
August 11	7.9	--	7.4	-	6.7	2.5
August 12	7.2	--	6.5	--	5.2	1.8
August 15	9.0	--	6.5	5.2	4.5	1.0
August 17	12.4	--	7.5	5.5	--	--
August 20	5.6	--	--	--	--	--
August 22	6.5	6.0	5.9	5.6	--	0.9
August 25	8.0	6.6	6.2	5.4	5.0	0.7
August 26	8.6	5.6	5.3	5.2	5.1	0.4
August 30	5.6	4.4	3.8	3.2	3.0	0.5
August 31	4.2	3.2	3.2	3.2	2.4	0.2
September 1*	4.2	3.6	3.2	3.2	0.4	--
September 1**	9.7	8.0	5.4	2.1	0.4	--
September 1***	10.8	10.2	8.2	3.2	0.4	--
September 2	4.0	3.2	3.0	--	0.8	--
September 5	11.9	11.5	4.4	3.8	3.2	3.0
September 7	4.6	4.2	3.8	3.8	3.8	3.8
September 8	10.0	10.0	9.8	6.8	4.6	1.4
September 9	6.2	6.2	6.2	6.1	--	5.6

* 9:00 a.m.
** 1:30 p.m.
*** 4:45 p.m.